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PREFACE.

I HAVE endeavoured in this book to explain the elementary facts connected with the Theory of Heat, so far as a knowledge of them is required by the University of Cambridge in the General Examination for the ordinary B.A. degree.

When I was preparing this, the Sixth, Edition for the press, I was informed that by the addition of a small amount of fresh matter the book might be adapted to the requirements of many other examinations, as, for example, Cooper's Hill Entrance, Army, Woolwich, Science and Art Department, Oxford and Cambridge Local, Oxford and Cambridge Schools, and Civil Service.

This additional matter is given in the *Appendices*, and no part of it is required in the General Examination.

In the preparation of the new part, and in the revision of the whole work, I have had the advantage of the assistance of Mr. W. T. GOOLDEN, M.A., Science Master at Tonbridge School. I gratefully acknowledge the improvement made in the book by his hints and suggestions.

The present Edition contains solutions to all the numerical examples.

J. HAMBLIN SMITH.

CAMBRIDGE, *April* 1879.

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APPENDICES.

HEAT.

SECTION I.

GENERAL EFFECTS OF HEAT.

1. COMMON experience makes us acquainted with the fact that some bodies, when we approach or touch them, affect us with the sensation of warmth. The cause of this sensation is called HEAT.

2. Till the latter part of the last century heat was generally regarded as a material substance, an invisible, weightless fluid, causing by its entrance into our bodies the sensation of warmth, and by its departure the sensation of cold.

3. It has been conclusively proved that heat is not matter, but that the application of heat to a body causes a vibration of the minute particles composing the body; that this vibration increases in intensity as the body receives more heat; and that what in our sensation is *heat* is in the body nothing but *motion*.

4. We will first consider what knowledge about heat we can acquire by some simple experiments.

Place a hand near a fire; we perceive the sensation of warmth; consequently the cause of this sensation, heat, must be in operation. Place it nearer: the sensation is stronger; and therefore the cause is producing a stronger effect. The same holds if the fire is fiercer. We state these results in another way, by saying that the heat enters the hand more rapidly, or, that a greater amount of heat enters in any specified time. Also, if we hold the hand near the fire *for a longer time,* it will grow warmer, that is, more heat enters, the longer we hold it in the same position.

5. Next, to insure regularity of burning and emission of heat, take a spirit lamp, and let it burn with considerable strength, so that its effects may be more marked; and

(*a*) Hold a piece of iron near the lamp, in the flame, and touch it at intervals. We find the sensation of heat stronger each time we touch the iron, that is, the *power of the iron to give out heat increases* the longer it remains in the flame.

(*b*) Take a glass tube with a bulb at the end, partly filled with mercury, and hold the bulb in the flame. The mercury rises up the tube, that is, *the volume of mercury has been increased* by the application of heat.

This result is also found in (*a*), but the *increase in the volume* of the iron is so small that it cannot be perceived without minute and careful measurement.

(*c*) Suspend a lump of ice, in a vessel of glass, in the flame. The ice melts, that is, there has been a *change*

of state from the solid to the liquid state. After this, if the water is kept in the same position, and the hand is dipped into it at intervals, we find, as in (*a*), that its power of giving out heat increases.

(*d*) If the water remains over the flame long enough, and the flame is strong enough, the water will begin to boil away, that is, it will be turned into steam. Here we have another *change of state*, from the liquid to the gaseous state.

In (*c*) and (*d*) there is a change in volume; in (*d*) an increase; in (*c*) a decrease, when the ice melts, and for some little time afterwards, and then there is an increase till the water begins to boil.

6. These experiments show the various effects produced by the entrance of heat into bodies, and we see that we may have

(i) A change in the power of the body to give out heat.

(ii) A change of volume.

(iii) A change of state.

TEMPERATURE.

DEF. "*The temperature of a body is its thermal state considered with reference to its power of communicating heat to other bodies.*"—*Maxwell.*

When this power increases, the temperature is said to *rise*; when it decreases, the temperature is said to *fall*.

8. We now proceed to explain how changes in temperature may be accurately determined; and first we will explain how a change of temperature in one body indicates a change of temperature in an adjacent body.

9. Heat can be transferred from one body to another. A smoothing-iron, such as is used by hatters and tailors, when placed on a heated stove, rapidly receives heat from the stove, and soon becomes too hot for us to touch. If we then remove it from the stove and place it on a cold iron stand, we shall find that heat is gradually communicated from the hot to the cold body, and that the temperature of the former is continually decreasing, while that of the latter is continually increasing.

10. "Hot bodies cannot be placed in contact with, or in the neighbourhood of, colder ones, without communicating to these part of their heat. When a lump of hot iron is taken out of the fire, how can we prevent it from communicating its heat to the surrounding matter? Lay it on the ground, or on a stone, it very quickly communicates to them a part of its heat; lay it on wood, or any other vegetable matter, it heats them in a very short time to such a degree as to set them on fire: let it be suspended in the air by a wire, it communicates heat to the air in contact with it."—*Black.*

11. Now imagine a cylindrical glass vessel A to be

filled with *cold* water and placed in a larger cylindrical vessel *B*; and suppose the space between the exterior surface of *A* and the interior surface of *B* to be filled with *hot* water. The water in *A* at once begins to gain heat, and the water in *B* loses heat; and this process goes on till the water in both vessels is in such a state that no more heat passes from *B* to *A* than that which passes from *A* to *B*. The water in both vessels is then said to be *at the same temperature.*

12. Black, in 1767, made important discoveries in reference to what he called the *equilibrium of heat*, and enunciated the following principle: "We must adopt, as one of the most general laws of heat, that all bodies communicating freely with each other, and exposed to no inequality of external action, acquire the same temperature."

This law of heat is included in that now known as *Prevost's Theory of Exchanges*, which may be stated thus:—

All bodies communicating freely with each other, and exposed to no inequality of external action, are constantly giving out and receiving heat; and the higher the temperature, the more heat is given out; so that a body of a temperature higher than that of a second body gives out more heat to that second body than it receives from it, and thus the first falls and the second rises in temperature, till their temperatures are equal, and then each keeps giving to the other as much heat as it receives from it.

Hence we obtain the following definition :—

Two bodies are said to have the same temperature, when neither parts with heat to the other in excess of the heat that it receives from the other, when they are put in contact.

13. Another consequence of imparting heat to bodies is the expansion of their volume. In the case of *solids* this effect is almost universal. If a polished cylinder of tin, which just passes through a ring, be heated to the temperature of boiling water, it will no longer pass through the ring, and will be found enlarged in all its dimensions. When the cylinder has been cooled it resumes its original volume, and will again pass through the ring.

An exception to this law is observed in the behaviour of stretched india-rubber, which contracts in length under the influence of heat.

14. The wheelwright and the cooper avail themselves of the tendency of iron to contract while it cools. A tire or hoop of red-hot iron is securely fastened to the rim of a wheel or the surface of a cask, and then is suddenly cooled by the application of cold water; the iron contracts, and binds the work with great force. The rivets of armour-plates are made red-hot before they are driven in.

"This force of expansion requires often to be carefully guarded against. Iron clamps built into furnaces frequently destroy, by their expansion and contraction,

the masonry which they are intended to support. In laying down pipes for the conveyance of gas and water, it is necessary to fit the lengths into sockets where the material used as stuffing to tighten the joint allows sufficient play for the alterations in length of the metal by changes of temperature. For the same reason a small interval is left between the ends of the iron bars in laying down a line of rails. Each tube of the Britannia Bridge, across the Menai Straits, is liable from changes of temperature, in the course of twenty-four-hours, to an elongation and contraction varying from half an inch to three inches."—*Miller*.

15. "The expansion caused by heat causes some bodies to crack and break in pieces when they are suddenly heated or cooled. When, for example, heat is suddenly applied to a part of a glass vessel that is not very thin, the heat expands that surface of the glass to which it is applied, and continues to expand it more, before it can penetrate to the other surface; as this last is not yet expanded, the glass is necessarily strained or stretched as if a force were applied to alter its form, and this force it cannot long withstand on account of its brittleness. It is therefore split or broken. And the same must happen to bodies of this kind when, after being heated, they are suddenly cooled. In both cases the fissure always begins in the coldest side. Thus if hot water be poured suddenly into a cold glass, the glass may be cracked from the outside, and if the bottom of a

cold glass be set in a basin of hot water, the glass may be cracked from the inside."—*Black.*

16. In the case of *fluids* the expansion attending the application of heat is more apparent. If oil or spirit of wine be put in a round glass with a long and slender neck, so as to fill only the round body of glass, and if the glass be then set in hot water, the application of heat will cause the fluid to swell and rise in the neck.

17. A remarkable exception to the law of expansion of bodies under the influence of heat occurs in water. This fluid expands during its passage from the liquid to the solid state. As water cools, it contracts, till it reaches a certain temperature; but shortly before it freezes it begins to expand, and continues to expand till it becomes ice.

The expansion of water during its conversion into ice is shown by the fact that ice swims on water.

The expansive force of water when freezing causes water-pipes to burst, and stones in the pavement to be raised or loosened.

Ice cooled below the freezing point contracts in volume like other solids.

18. When heat is applied to *gases*, the effect is to expand them with great rapidity. When a liquid passes into the gaseous state, the process is called *vaporisation.* "The liquid is by this process converted into an elastic vapour—that is, a fluid extremely rare, light and expansive, like air; capable, like it, of being easily

reduced into less space by external pressure, and resisting, like it, the force which thus compresses it."—*Black.*

19. STEAM is the transparent and invisible vapour that rises from water *at the boiling point.*

20. "Put a teaspoonful of water into a globe of glass capable of holding several gallons, and suppose this vessel exhausted of air. If we apply heat to the globe we shall presently perceive the water to gradually disappear, so that the globe will seem empty. But the fact is, that it is completely filled with the water, now existing in the form of a perfectly transparent vapour; for if the heat be still further increased, the expansive force of what now fills the globe will also increase to such a degree as even to burst it."—*Black.*

SECTION II.

THERMOMETRY.

21. Since bodies have their volume altered by heat, the change in temperature of a body may be ascertained by observing its change of volume, or by observing the change in volume of another body placed in thermal contact with it. (See also Art. **12.**)

A body which is used to indicate temperature by an observation of its volume is called a *thermometer.*

22. A thermometric substance should possess the following properties :—

(*a*) It must have a special volume, different for every possible temperature.

(*b*) It should expand regularly.

(*c*) It should be easily obtainable in a state of purity.

(*d*) It should quickly acquire the temperature it is required to indicate.

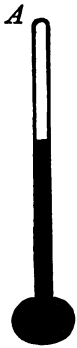

FIG. 1.

The substances most commonly used for thermometers are the fluids mercury, alcohol, and air, enclosed in a glass bulb having a fine tube attached. The bulb contains the fluid, which extends part of the way up the tube. The space between the fluid and the top of the tube is destitute of air.

If the fluid in the instrument be subjected to an increase of heat, it expands and rises higher in the tube.

23. Thermometers are usually graduated into volumes which indicate the temperatures of the instrument at those volumes.

A thermometer, when surrounded by melting ice at the ordinary pressure of the atmosphere, always assumes the same volume, and also when placed in the steam of water boiling under the same pressure of the air.

Under normal conditions of pressure, therefore, the freezing point and boiling point of water are fixed temperatures.

24. To graduate a thermometer it is placed in pounded ice in a *melting* state; the fluid shrinks, the column shortens, and finally becomes stationary. The point at which it rests is marked; this is the *freezing point* of the thermometer.

The instrument is next placed in the vapour of water boiling under average atmospheric pressure: the fluid expands, the column lengthens, and finally becomes stationary. The point at which it rests is marked; this is the *boiling point* of the thermometer.

The space between the freezing point and the boiling point is divided into equal spaces called degrees.

In the centigrade thermometer the freezing point is marked 0°, and the boiling point 100°.

In Fahrenheit's thermometer freezing point is marked 32°, and boiling point 212°.

In Reaumur's thermometer freezing point is marked 0°, and boiling point 80°.

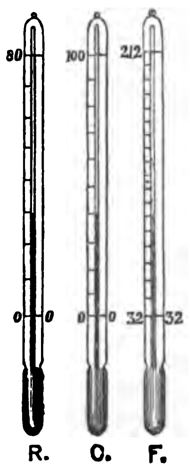

FIG. 2.

25. Having given the number of degrees on Fahrenheit's thermometer, to find the corresponding number of degrees on the centigrade thermometer:—

Let AM be the line at which the mercury stands at freezing point, and BN the line at boiling point.

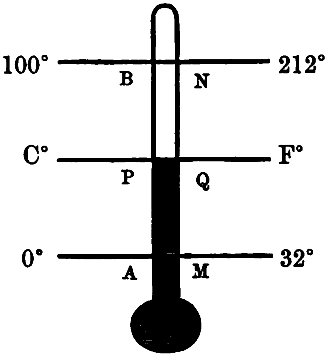

FIG. 3.

Then AM and BN are marked 0° and 100° on the centigrade scale, and 32° and 212° on the Fahrenheit scale.

Let the mercury stand at the line PQ, and suppose the graduations on the scales to be $C°$ and $F°$ respectively.

$$\text{Now } \frac{AP}{AB} = \frac{MQ}{MN},$$

$$\text{or } \frac{C}{100} = \frac{F-32}{212-32},$$

$$\text{or } \frac{C}{100} = \frac{F-32}{180};$$

$$\therefore \frac{C}{5} = \frac{F-32}{9},$$

and from this equation we can find C when F is given, and F when C is given.

26. To compare the scales of the centigrade and Reaumur's thermometer, we proceed in the same way, putting 0°, $R°$, 80° instead of 32°, $F°$, 212° respectively, and we obtain :—

$$\frac{C}{100}=\frac{R}{80}, \text{ or } \frac{C}{5}=\frac{R}{4};$$

hence the three scales are thus connected—

$$\frac{C}{5}=\frac{F-32}{9}=\frac{R}{4}.$$

27. The following examples will show how to find the number of degrees marked on any one of the three scales, when the number marked on one of the other scales is given.

Ex. 1. What reading on the centigrade scale corresponds to 56° Fahrenheit?

$$\text{Since } \frac{C}{5}=\frac{F-32}{9},$$

$$\text{and } F=56,$$

$$\frac{C}{5}=\frac{56-32}{9};$$

$$\therefore\ 9C=5\times 24,$$

$$\therefore\ C=\frac{120}{9}=13\tfrac{1}{3},$$

$\therefore$ the reading on the centigrade scale is $13\frac{1}{3}°$.

Ex. 2. What reading on the Fahrenheit scale corresponds to 14° centigrade?

$$\text{Since } C=14,$$

$$\frac{14}{5}=\frac{F-32}{9};$$

$$\therefore\ 126=5F-160,$$

$$\therefore\ 5F=286,$$

$$\therefore\ F=57\tfrac{1}{5},$$

that is, the reading on the Fahrenheit scale is $57\frac{1}{5}°$.

Ex. 3. If the sum of the readings on a centigrade and a Reaumur be 90, what is the reading on each?

Here we have two equations, from which we can find C and R.

$$\frac{C}{5}=\frac{R}{4}\ \ldots\ldots (1)$$

$$C+R=90\ \ldots\ldots (2)$$

$$\left.\begin{aligned} \therefore 4C &= 5R \\ 4C+4R &= 360 \end{aligned}\right\};$$

$$\therefore 4R = 360-5R,$$

$$\therefore 9R = 360,$$

and so $R=40$ and $C=50$.

EXAMPLES.

(1.) Give the number of degrees in the centigrade and Reaumur's scale respectively that correspond to the following readings on Fahrenheit's scale:—

(i) 30°, (ii) 45°, (iii) 56°, (iv) 0°, (v) −7°, (vi) −45°.

(2.) Give the number of degrees in the centigrade and Fahrenheit's scale respectively that correspond to the following readings on Reaumur's scale:—

(i) 5°, (ii) 20°, (iii) 0°, (iv) −18°, (v) −64°, (vi) 120°.

(3.) Give the number of degrees on Fahrenheit's and Reaumur's scales respectively that correspond to the following readings on the centigrade scale:—

(i) 16°, (ii) 45°, (iii) 110°, (iv) 0°, (v) −15°, (vi) −24°.

(4.) At what temperature are the readings on Reaumur, centigrade, and Fahrenheit proportional to 4, 5, 25?

(5.) If the sum of the readings on a centigrade and Fahrenheit be 60, what is the reading on each?

(6.) At what temperature will the degrees on Fahrenheit be five times as great as the corresponding degrees on the centigrade?

(7.) At what point do Fahrenheit and the centigrade mark the same number of degrees?

(8.) Show how to graduate a thermometer on whose scale 20° shall denote the freezing point, and whose 80th degree shall indicate the same temperature as 80° Fahrenheit.

(9.) The sum of the number of degrees indicating the same temperature on the centigrade and Fahrenheit is 88; find the number of degrees on each.

(10.) At what temperature will the degrees on Fahrenheit be three times as great as the corresponding degrees centigrade?

(11.) The number of degrees indicated at the same instant by a centigrade and a Fahrenheit's thermometer are as 5 : 17; determine the temperature.

(12.) What is the temperature when the number of degrees on the centigrade is as much below zero, as that on Fahrenheit's is above zero?

(13.) One thermometer marks two temperatures by 9° and 10°; another thermometer by 12° and 14°; what will the latter mark when the former marks 15°?

(14.) One thermometer marks two temperatures by 8° and 10°, another thermometer by 11° and 14°; what will the latter mark when the former marks 16°?

(15.) If the difference of the readings on Fahrenheit and Reaumur be 47, what are the readings? If the difference increase by a given number of degrees, find how much each of the thermometers has risen.

(16.) In De Lisle's thermometer (which is much used for scientific investigation in Russia) the freezing point is 150° and the boiling point zero. What degree of this thermometer corresponds to 47° Fahrenheit?

(17.) At what temperature is the sum of the readings on Reaumur, centigrade, and Fahrenheit 212?

28. The advantages of employing mercury in the construction of a thermometer are:—

(*a*) It is a liquid that may be readily obtained in a state of purity.

(*b*) It gives out and takes in heat very quickly, and therefore soon comes into equilibrium of temperature with a body in contact with it.

(*c*) Its capacity for heat is very small, so that if it be brought into contact with a heated body, from which it takes heat, the temperature of the body is but slightly decreased by the abstraction of the small quantity of heat required to raise the temperature of the mercury up to that of the body. (See also Art. **56.**)

29. In the construction of the ordinary mercurial thermometer observe :—

(*a*) That for an accurate instrument, the tube must be so graduated that the spaces between the divisions may contain equal volumes of mercury.

In order to be able to do this, before the instrument is filled, a small quantity of mercury is introduced into the tube and its length is observed, as it moves along from one end to the other. The degrees are afterwards made, proportional to these lengths in the respective parts of the tube.

(*b*) The way in which the mercury is made to enter a narrow tube.

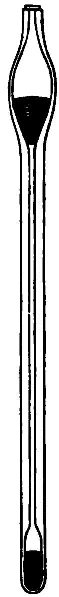

Fig. 4.

The tube having been cut of the proper length, one end is melted by heat, and then blown into a bulb: the other end is left open. The bulb is then warmed, in order to expel some of the air from it, and the open end of the tube is placed in a vessel of mercury. During the cooling of the tube some mercury is forced, by the pressure of the outside air, through the tube into the bulb. This mercury is now boiled, so that the air may be entirely expelled, and nothing remain in the instrument but mercury and mercury vapour, and its open end is again submersed. When the tube cools it becomes entirely filled with mercury.

Sometimes another and larger bulb is blown near the

upper end of the tube, open at both ends. This is filled first, and then, the lower bulb being treated in the way described above, the air is expelled through the mercury in the upper bulb.

(*c*) The vacuum at the top of the tube is obtained thus: The bulb of the thermometer is immersed in some oil heated to a temperature a little above the highest which the instrument will be required to register, and the flame of a blowpipe is applied to a point in the full tube, so as to melt and seal it at a convenient length. As the mercury cools it contracts, and leaves the upper end of the tube empty.

TESTS OF THERMOMETERS.

30. A standard thermometer is kept at Kew by which other thermometers can be tested and corrected. The following are rough tests of the value of a thermometer when no standard instrument is at hand wherewith to test it :—

(*a*) When the bulb and stem, up to the top of the mercurial column, are immersed in melting ice, the top of the mercury should rest at 0° *C.*

(*b*) When the instrument is suspended in the vapour of water boiling under a certain atmospheric pressure, the mercury should rest at 100° *C.*

(*c*) When the instrument is turned upside down, some of the mercury should run down and completely fill the end of the tube; which it will not do if any air has been left in the instrument.

(*d*) A small column of mercury should be detached from the rest by a jerk, and made to pass, by inclining the tube, from one portion of the bore to another. If the scale be properly graduated, this column will fill an equal number of degrees in each part.

31. The fixed points in the thermometric scale, determined by the melting of ice and the boiling of water, were first suggested by Newton. Hooke had announced in 1664 that the temperature of melting snow is always the same. This is very nearly true, though the temperature is slightly lowered by an increase of pressure.

Hooke also announced, in 1684, that boiling water, under the same pressure, is always of the same temperature. This is not true, for water boils at a different temperature in vessels of different materials. But the steam rising from water boiling under the same pressure is, as nearly as possible, of the same temperature.

32. The glass tube of a thermometer, in consequence of its exposure to heat during the process of constructing the instrument, is found to contract gradually for some months; hence the mercury, when placed in melting ice, will stand somewhat higher than the freezing point on the scale. To avoid this error, the tube should not be graduated till some time after it has been filled.

33. Since mercury freezes at about $-39°$ *C*, it cannot be employed to determine very low temperatures, and

for this purpose alcohol is used as a thermometric substance, because it has never yet been frozen.

34. Two thermometers, with tubes of uniform bore, *filled with the same liquid*, whose freezing and boiling points have been accurately determined, will not necessarily agree at intermediate temperatures, because the glass of one tube may not expand (or contract) in the same degree as the glass of the other. To avoid this difference as much as is possible, the best thermometers in this country are made of the same kind of glass.

When the thermometers are *filled with different liquids*, they do not in general agree at intermediate temperatures, because the liquids do not expand uniformly.

MAXIMUM THERMOMETER.

35. This is an instrument constructed to mark the highest temperature that occurs within a given time.

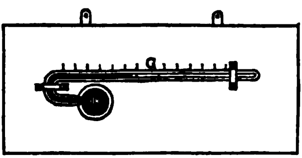

FIG. 5.

A simple form of the instrument is that in which the stem of a common thermometer is fixed horizontally, with a small piece of iron wire (c) moving freely in the tube. When the temperature rises, the mercury pushes the wire before it; but when the temperature falls, the mercury contracting leaves the wire in the furthest position to which it had been driven,

and thus the maximum temperature between two observations is discovered.

36. An instrument of simpler construction and more trustworthy action is that invented by Negretti and Zambra, called the

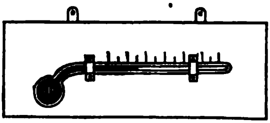

Fig. 6.

Self-registering Maximum Thermometer. The thermometer tube above the mercury is entirely free from air, and at a point in the bend of the tube above the bulb is inserted and fixed with the blowpipe a small piece of solid glass or enamel, which acts as a valve, allowing the mercury during its expansion to pass on one side of it, but not allowing it to return when the thermometer cools, on account of the friction between the mercury and the enamel. Thus the instrument, when placed horizontally, marks the highest temperature reached since the last observation. The mercury is returned to the bulb by lowering the bulb end of the thermometer, when the force of gravity will cause the mercury in the tube to unite with that in the bulb, and thus prepare the instrument for future observation.

37. A form of maximum thermometer much in use is that invented by Phillips, in which about half an inch of the mercury in the stem

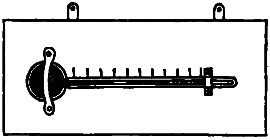

Fig. 7.

is separated from the remainder by a small portion of *air*. The instrument is placed horizontally, and the detached part of the mercury is *pushed on* when the mercury in the bulb expands, but it is *not drawn back* when the mercury in the bulb contracts.

MINIMUM THERMOMETER.

38. This is an instrument constructed to mark the lowest temperature that occurs within a given time.

The fluid employed is alcohol; the instrument is placed horizontally; and immersed in the fluid in the tube is a small index of enamel, *n*. As the alcohol recedes, it carries with it the index, with one extremity just at the end of the fluid column; as the alcohol expands, it does not carry the index with it, and thus the lowest temperature between two observations is recorded.

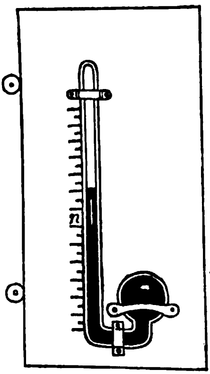

FIG. 8.

Casella has succeeded in making a mercurial minimum thermometer, which is an exceedingly good and trustworthy instrument, but the difficulty and expense of constructing it are so great that it has not hitherto come into general use.

THE AIR THERMOMETER.

39. A glass tube, open at one end, is blown into a bulb at the other. The bulb is warmed, and the tube

is then set upright, with its open end in some coloured liquid. As the bulb cools, the air in it occupies less space, and the liquid rises in the tube. The liquid sinks when the temperature of the air in the bulb is increased.

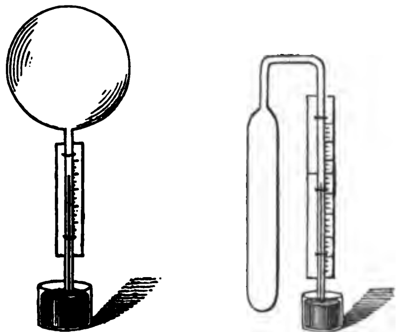

FIG. 9.

By affixing a graduated scale to the tube, the extent of increase or decrease in the column of liquid can be estimated.

40. A simpler form of the air thermometer is that of a long tube of uniform bore, closed at one end, and standing with the open end uppermost, the air (or gas) in the lower part of the tube being separated from the external air by a small column of mercury. If the lower part of the tube be warmed (or cooled), the index rises (or sinks) very rapidly.

41. The advantages of an air thermometer are :—

(i) That it is easily made.

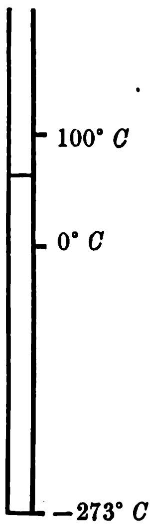

FIG. 10.

(ii) That the column of liquid (or the index) rises or sinks further, for a given change of

temperature, than the column in a thermometer in which mercury is employed.

(iii) That the changes of temperature are indicated *rapidly*.

(iv) "The scale of temperature, as indicated by an air thermometer, has this advantage over the scale indicated by mercury, or by any other liquid or solid, that, whereas no two liquid or solid substances can be made to agree in their expansion throughout the scale, all the gases agree with one another."—*Maxwell.*

(v) Air expands uniformly, so that an increase of temperature of one degree is always indicated by the same increase in volume in any part of the scale; but liquids expand at an increasing rate as their temperature rises, so that the degrees on a liquid thermometer ought to be longer in the upper part of the scale than in the lower part.

The disadvantage of such a thermometer is, that the height of the column of liquid (or the index) is affected by the external pressure of the atmosphere, and that we cannot estimate the temperature, as indicated by the air thermometer, without taking into account the height of the barometer at the same time and place.

42. Another mode of employing mercury as a thermometric substance is referred to in Appendix II.

SECTION III.

EXPANSION OF GASES.

43. The following are the experimental laws connecting the pressure, volume, and temperature of a gas :—

LAW I. *So long as the temperature remains the same, the volume occupied by a gas varies inversely as the pressure.*

This is known as Boyle's law, or as Mariotte's law.[1]

LAW II. *So long as the pressure remains the same, the volume of a gas, when raised from* 0° *C to* 100° *C, increases, for each degree centigrade, by the same fraction of its volume at* 0° *C, whatever be the nature of the gas.*

This is called the law of Charles, or of Gay-Lussac.

LAW III. *So long as the volume of a gas remains the same, the pressure increases uniformly with the temperature.*

44. Suppose the horizontal section of the tube of the air thermometer, described in Art. 38, to be one square inch. If at a temperature of 0° *C* the air in the tube stand at the height of about 30 inches, at 100° *C* the air will stand at the height of about 41 inches. Hence, supposing the rate of increase uniform, for each degree centigrade of the rising temperature the volume of the air will have increased by $\frac{11}{3000}$ of its volume at the freezing point.

Now $\frac{11}{3000}$ is nearly equivalent to $\frac{1}{273}$, and if we take the latter fraction as the measure of the increase of volume of the air, the volume of air will be *doubled* at a temperature of 273° *C*.

Again, supposing the volume of air to *decrease* by the

[1] The pressure of a gas is sometimes measured by the height of a column of mercury supported in a tube closed at its upper end, and whose lower end dips beneath the surface of some mercury exposed to the pressure of the gas. The height of the column above the exposed surface of the mercury is proportional to the pressure.

same fraction of its volume at 0° *C* for each degree centigrade as the temperature is lowered below the freezing point, it follows that the volume of air in the tube would be reduced to zero at a temperature of −273° *C*.

The reading of −273° *C* at the bottom of the tube is called *the absolute zero point* of the air thermometer. Temperatures reckoned from this point are called *absolute temperatures.*

Hence to obtain the absolute temperature we must add 273 to the measure of the temperature on the centigrade scale: thus the absolute temperature of 35° *C* is 308° *C*, and the absolute temperature of −18° *C* is 255° *C*.

45. A more exact approximation to the rate of increase (or decrease) in the volume of the air in the tube of the air thermometer is given by the following law: If the pressure remain constant, every increase of temperature of 1° centigrade produces in a given mass of air an expansion of ·003665 of its volume at 0° *C*.

This decimal ·003665 is called the *co-efficient of expansion* of air, and it is represented by a.

Hence, if V_0 be the volume of air at temperature 0° *C*, and V_t be the volume of air at temperature t° *C*, under constant pressure,

$$\begin{aligned} V_t &= V_0 + a\,t\,V_0 \\ &= V_0\,(1 + a\,t) \end{aligned}$$

The value of a is nearly the same for all gases, and it varies but little with the variation of the pressure.

Since $V_t = V_0\ (1 + at)$, if $V_{t'}$ be the volume of the same air at another temperature t' we have also

$$V_{t'} = V_0\,(1 + at')$$

hence, dividing one equation by the other, we get for an expression connecting the volume of a gas at one temperature with its volume at any other temperature,

$$V_t\,(1 + at') = V_{t'}\ (1 + at).$$

46. The conception of absolute temperature enables us to simplify the expression of the three laws; for if the measures of the volume, pressure, and absolute temperature of a mass of gas be V, P, T under one set of conditions, and v, p, t under another set of conditions,

$$VPt = v\,p\,T.$$

This equation may be employed in working examples, but for the purposes of this treatise it seems better to illustrate the application of the laws by the unitary method, thus:—

LAW I. *Ex.* At a constant temperature a mass of air occupies 25 cubic feet under a pressure of 10 lbs.; what space will it occupy under a pressure of 24 lbs.?

$$\text{Space occupied under pressure of}\left\{\begin{array}{l} 10 \text{ lbs. is } 25 \text{ cubic feet.} \\ 1 \text{ lb. is } (25 \times 10) \text{ cubic feet.} \\ 24 \text{ lbs. is } \dfrac{25 \times 10}{24} \quad \text{,,} \quad \text{,,} \\ \qquad\quad \text{or } 10\tfrac{5}{12} \quad \text{,,} \quad \text{,,} \end{array}\right.$$

LAW II. [In examples reduce the temperatures to absolute temperatures on the centigrade scale.]

Ex. 1. A mass of gas occupies 510 cubic feet at 27° *C*; what space will it occupy at 67° *C* under the same pressure?

The absolute temperatures are 27° + 273°, or 300° *C*,
and 67° + 273°, or 340° *C*.

$$\text{Space occupied at abs. temp. of}\left\{\begin{array}{l} 300^\circ \text{ is } 510 \text{ cubic feet.} \\ 1^\circ \text{ is } \dfrac{510}{300} \quad " \quad " \\ 340^\circ \text{ is } \dfrac{510 \times 340}{300} \text{ cubic ft.} \end{array}\right.$$

or 578 „ „

Ex. 2. A mass of gas occupies 216 cubic inches at 59° *F*; what space will it occupy at 113° *F*, the pressure remaining constant?

Since 59° $F = \frac{5}{9}$ (59 − 32)° *C*, or 15° *C*,
and 113° $F = \frac{5}{9}$ (113 − 32)° *C*, or 45° *C*,
the absolute temperatures are 288° *C* and 318° *C*.

$$\text{Space occupied at absolute temp. of}\left\{\begin{array}{l} 288^\circ C \text{ is } 216 \text{ cubic inches.} \\ 1^\circ C \text{ is } \dfrac{216}{288} \quad " \quad " \\ 318^\circ C \text{ is } \dfrac{216 \times 318}{288} \text{ cub. in.} \end{array}\right.$$

or 238·5 „ „

LAW III. *Ex.* A quantity of gas exercises a pressure of 25 lbs. at a temperature of 42° *C*, and occupies a space of 12 cubic inches; what will the pressure be when, at a temperature of 56° *C*, it occupies the same space?

The absolute temperatures are 315° *C* and 329° *C*.

At abs. temp. of 315° the pressure is 25 lbs.

"	"	1°	"	"	$\frac{25}{315}$ lbs.
"	"	329°	"	"	$\frac{25 \times 329}{315}$ lbs.
					or $26\frac{1}{9}$ lbs.

47. In examples involving a variation of *two* conditions—that is, for instance, when a gas occupies a given space at a given temperature and under a given pressure, and we require to find the space it will occupy when the temperature and pressure are both changed—we may still apply the unitary method of solution.

Ex. 1. A certain quantity of air occupies 67 cubic inches when the temperature is 10° *C*, and the barometer at 28 inches; how many cubic inches will it occupy at 0° *C*, with the barometer at 30 inches, taking the co-efficient of cubical expansion as $\frac{1}{273}$ for 1° *C*?

Here the abs. temps. are 283° *C* and 273° *C*.

Volume with temp. of	283° and press.	28 in.	is	67 cub. in.	
	1°	"	28	"	$\frac{67}{283}$ " "
	1°	"	1	"	$\frac{67 \times 28}{283}$ cub. in.
	273°	"	30	"	$\frac{67 \times 273 \times 28}{283 \times 30}$ cub. in.
					or $60\frac{458}{1415}$ cub. in.

Ex. 2. If the density of air at 50° *F*, when the barometer is at 30 inches, be called unity, what will be the density of air at 32° *F* with the barometer at 29 in.?

The absolute temperatures are 283° *C* and 273° *C*.

Hence, as before, the measure of volume at 273° *C* and pressure 29 inches is $\frac{1 \times 273 \times 30}{283 \times 29}$; and since the density is inversely as the volume, measure of density is $\frac{283 \times 29}{273 \times 30}$, or $1\frac{17}{8190}$.

EXERCISES ON THE EXPANSION OF GASES.

The co-efficient of expansion of a gas may be taken as $\frac{1}{273}$, unless it is otherwise stated.

(1.) At a constant temperature a mass of air occupies 18 cubic feet under a pressure of 7·5 lbs.; what space will it occupy under a pressure of 25 lbs.?

(2.) A mass of air occupies 28·5 cubic feet under a pressure of 15 lbs.; what space will it occupy under a pressure of 20 lbs., the temperature being constant?

(3.) 1365 cubic feet of gas, under a constant pressure, are heated from 0° *C* to 50° *C*; what will be the volume of the gas at the last temperature?

(4.) A mass of gas occupies 864 cubic inches at 15° *C*; what space will it occupy at 40° *C*, at the same pressure?

(5.) If 30 cubic inches of air at 0° *C* occupy 41 cubic inches at 100° *C* under the same pressure, find the temperature of the absolute zero point of the thermometer in degrees centigrade.

(6.) A quantity of air occupies 75 cubic inches under

a pressure of 29·5 inches of mercury and a temperature of 45° *C*; what space will it occupy under a pressure of 30 inches of mercury and a temperature of 35° *C*?

(7.) A quantity of air, which occupies $1\frac{10}{273}$ cubic feet at 10° *C* and under a pressure of 30 inches of mercury, is raised to 15° *C* and the pressure reduced to 29 inches; find its volume.

(8.) A quantity of gas occupies 26 inches at a temperature of 59° *F* and under a pressure of 29 inches of mercury; how much space will it occupy when the temperature rises to 68° *F* and the pressure to 50 inches?

(9.) If the air in a fire balloon, the volume of which is 373 cubic feet, be raised to a temperature of 100° *C*, the temperature of the surrounding air being 0° *C*, show that the balloon will not ascend if its weight exceed $7\frac{1}{2}$ lbs., assuming the weight of a cubic foot of air at the atmospheric pressure and 0° *C* to be 1·2 oz.

(10.) If the compressed air in a flooded coal-pit occupied 2500 cubic feet at a temperature of 50° *F* and under a pressure of 70 inches of mercury, how much space would it fill at a temperature of 60° *F* and under a pressure of 29·5 cubic inches of mercury?

(11.) If the density of air at 15° *C*, with the barometer at 30 inches, be taken as the unit of measure-

ment, what is the measure of the density of air at 36° F, with the barometer at 29·5 inches?

(12.) If 120 cubic inches of gas, whose temperature is 35° C under a pressure of 30 inches, has its temperature raised to 46° and its pressure reduced to 25 inches, find its volume.

(13.) A given quantity of gas, kept at a constant pressure, in being raised in temperature from 0° to 100° C, expands in volume in the ratio of 1 to 1·366; find the zero of absolute temperature in the centigrade scale.

(14.) Find the volume, at 45° C and under a pressure of 1500 millimetres of mercury, of a quantity of air which, at 27° C and under a pressure of 760 millimetres of mercury, occupies 10 cubic feet.

(15.) The density of oxygen gas is 1·10563 times the density of air, at the same temperature. At what temperature will oxygen have the same density that air has at 0° C, the pressure remaining unchanged?

(16.) The co-efficient of expansion of air for 1° centigrade being 0·003665, what is the co-efficient of expansion for 1° Fahrenheit?

(17.) At what temperature will oxygen, at a pressure of 5 inches of mercury, have the same density as hydrogen at 0° C and at a pressure of 40 inches, if, at the same temperature and pressure, oxygen has 16 times the density of hydrogen?

SECTION IV.

EXPANSION OF SOLIDS.

48. Suppose a piece of lead in the form of a perfect cube, of which the edge is 1 inch, to be subjected to an increase of temperature. The result will be an increase in

(i) The length of each edge of the cube.
(ii) The area of each side of the cube.
(iii) The volume of the cube.

(I.) It is found by experiment that an increase of temperature of 1° centigrade will increase the length of the edge of such a cube of lead by about ·000028 of an inch.

This decimal ·000028 is called *the co-efficient of linear expansion* of lead.

DEF. *The co-efficient of linear expansion of a solid is the increase in length of a unit of length of the solid when its temperature is increased from* 0° *to* 1° *centigrade.*

This co-efficient varies for different substances; for example, the co-efficient of linear expansion of gold is about half that of lead, or ·000014.

The co-efficients of linear expansion increase slightly with an increase of temperature, that is, the length of the edge of the cube is slightly more increased as the temperature is raised from 21° to 22° than the increase as the temperature is raised from 20° to 21°.

But if we suppose that the expansion is regular as the temperature rises, and if

l_0 be the measure of the length of a solid body at 0° C,

l_t the measure of the length of the body at t° C,

k the co-efficient of linear expansion,

$$l_t = l_0 + l_0 \, t \, k$$
$$= l_0 (1 + t\,k).$$

Ex. If a line of railway be laid with rails, which are 6 yards long, at 0° C, show that, to allow for the expansion due to an increase of temperature of 55°, the distance between two consecutive rails must not be less than about $\frac{7}{50}$ of an inch.

The co-efficient of the linear expansion of iron is ·000012.

Taking 1 inch as the unit of linear magnitude,

$$l_{55} = 216 \, (1 + 55 \times \cdot 000012) \text{ inches}$$
$$= 216 \times 1 \cdot 00066 \text{ inches.}$$
$$= 216 \cdot 14256 \text{ inches.}$$

Hence the space between two consecutive rails must be more than ·14 of an inch, that is, more than $\frac{7}{50}$ of an inch.

(2.) If k be the measure of the co-efficient of linear expansion, the area of each side of the cube, which at temperature 0° C was 1 square inch, will at temperature 1° C be $(1 + k)^2$ square inches, or $(1 + 2k + k^2)$ square inches.

Now, as k is very small, k^2 may be neglected, and the

new area may be taken as $(1 + 2k)$ square inches, that is, the increase of area is $2k$ square inches.

Hence, the co-efficient of superficial expansion is $2k$, or *twice* the co-efficient of linear expansion.

(3.) The increased volume of the cube will be $(1 + k)^3$ cubic inches, or $(1 + 3k + 3k^2 + k^3)$ cubic inches.

Neglecting the very small numbers $3k^2$ and k^3, the new volume may be taken as $(1 + 3k)$ cubic inches, that is, the increase of volume is $3k$ cubic inches.

Hence, the co-efficient of cubical expansion is $3k$, or *three* times the co-efficient of linear expansion.

(A description of the method of determining the co-efficient of expansion of solids is given in App. I.)

EXERCISES ON THE EXPANSION OF SOLIDS.

The following may be taken as the co-efficients of linear expansion of the solids referred to in these exercises :—

Glass	·00000865.	Gold	·00001465.
Platinum	·00000875.	Copper	·00001715.
Cast-Iron	·00001125.	Brass	·00001875.
Wrought-Iron	·00001225.	Silver	·00001905.
Steel	·00001255.	Lead	·00002855.

(1.) The length of a brass rod at 0° *C* is 15 feet; find its length at 25° *C*.

(2.) A glass rod is 8 feet 6 inches long at 20° *C*; find its length at 45° *C*.

(3.) The length of a wrought-iron rail at 0° *C* is 5·5 feet; find its length at 40° *C*.

(4.) What must be the length of a rod of copper at 45° *C*, so that at 0° *C* it may be 12 feet in length?

(5.) A bar of gold is 16 inches in length at 10° *C*; what will be its length at 20° *C*?

(6.) The length of an iron-girder bridge at 0° *C* is 150 feet; what will be its length at 50° *C*?

(7.) The rails from London to Cambridge are $57\frac{3}{4}$ miles in length at 0° *C*; what will their length be at 25° *C*?

(8.) A brass measuring-bar, whose readings are true at 0° *C*, gives a reading of 28 inches at 15° *C*. What is the real length indicated?

(9.) A glass graduated tube, whose readings are true at 62° *F*, gives a reading of 30 inches at 52° *F*; what is the real length indicated?

(10.) Deduce from the above table the co-efficient of cubical expansion of glass for 1° *F*.

(11.) The standard metre is a platinum bar whose length is 39·37043 inches at 0° *C*, and the standard yard is a bar of bronze which measures 36 inches at 62° *F*. At what temperature will their lengths be exactly in the ratio of 13 to 12? (Co-efficient of bronze taken to be the same as that of brass.)

(12.) A barometer-maker wishes to graduate his brass scale on one side in inches true at 62° *F*, and on the other side in centimetres true at 0° *C*. What relation must the divisions for centimetres bear to those for inches in order that the graduation of both sides may

be effected at the same temperature? (1 centimetre = $\frac{1}{100}$ metre.)

(13.) A silver bar, compared with the standard yard, appears to be 36 inches long when both are at 50° *F*. What will be the length of the bar at 62° *F*, and what its length at 0° *C*?

(14.) A wrought-iron bar was found by Roy and Ramsden's method to expand from 28·5759 inches at 0° *C* to 28·8902 inches at 98° *C*. Thence deduce the co-efficient of expansion of wrought-iron. (*See* App. I.)

(15.) A plate of brass has an area of 15 square feet at 5° *C*; what is its area at 55° *C*?

(16.) A sheet of lead has a surface area of 48 square feet at 8° *C*; what is its area at 67° *C*?

(17.) A sheet of copper has a surface area of 23·5 square feet at 5° *C*; what is its area at 43° *C*?

(18.) An ingot of silver is 4 feet long, 2·5 feet broad, and its thickness is 8 inches, at 40° *C*; how many cubic inches will there be in its volume at 70° *C*?

(19.) A sphere of brass has a diameter of 14 inches at a temperature of 2° *C*; what will be the volume of the sphere at a temperature of 75° *C*? (Volume of a sphere $=\frac{4\pi r^3}{3}$.)

(20.) A glass vessel has a capacity of 50 cubic inches at a temperature of 10° *C*; what will be its capacity at a temperature of 100° *C*?

(21.) In the last example calculate the volume of air (estimated at 100° *C*) which would be expelled from the vessel during its rise in temperature.

(22.) When a body is weighed in air it loses weight equal to that of the air displaced by it. A closed empty glass vessel, weighing 1000 grains in air, whose temperature is 10° *C* and pressure 29 inches, has a volume at 0° *C* of 20 cubic inches. From this deduce its true weight in vacuo.

(1 cubic foot of dry air, at 0° *C* and 30 inches, weighs 566·5654 grains.)

(23.) The specific gravity of silver at 0° *C* is 10·5; what is its specific gravity at 100° *C*?

(24.) The specific gravity of brass at 0° *C* is 8·383; what is its specific gravity at 40° *C*?

(25.) The specific gravity of lead at 0° *C* is 11·352; what is its specific gravity at 65° *C*?

(26.) The volume of a mass of cast-iron being 245 cubic feet at 0° *C*, find its volume at 100° *C*.

(27.) The volume of a mass of platinum being 28·5 cubic feet at 0° *C*, find its volume at 56° *C*.

(28.) The density of mercury at 0° *C* being 13·598, find its density at 100° *C*, the co-efficient of expansion being taken as ·00018.

(29.) The co-efficient of expansion of iron wire is ·00001235, and the length of wire between a distant signal and the signal-box is 900 yards. If the wire has to be pulled through six inches to lower the signal from "danger," find what increase of temperature of the wire will allow the signal to return to "danger" after it has been lowered.

SECTION V.

EXPANSION OF LIQUIDS.

49. Liquids expand much more rapidly than solids under the influence of heat.

The lighter a liquid is, the greater generally is its expansion. Thus alcohol expands more than water, and water more than mercury.

In the case of liquids we only consider their cubical expansion, and as in the case of solids we define the co-efficient of cubical expansion of a liquid as the increase in the volume of a unit of volume of the liquid when its temperature is increased from 0° to 1° *C*.

50. The co-efficient of expansion increases for most liquids very rapidly as the temperature increases, but in the case of mercury the rate of expansion up to 100° *C* is nearly uniform, and it is found to be ·000181, or, expressed as a fraction, approximately $\frac{1}{5550}$.

This is the co-efficient of *absolute* expansion, that is, what would be observed if the vessel containing the mercury did not expand at the same time. The *apparent* expansion of mercury is that which is actually observed when it is heated in a vessel which expands at the same time, and this is, of course, less than the absolute expansion. For example, the co-efficient of apparent expansion of mercury in a glass tube for temperatures between 0° *C* and 100° *C* is found to be $\frac{1}{6480}$.

(This subject is treated of more fully in Appendix II.)

SECTION VI.

CALORIMETRY.

51. To measure quantities of heat we must have a unit of heat, called a *thermal unit,* as a standard of measurement.

Such a unit is the quantity of heat required to produce a definite effect, as, for example :—

(i) To convert a pound of ice at 0° *C* into water at 0° *C*, or

(ii) To raise a pound of water through one degree of temperature, as from 0° *C* to 1° *C*, or

(iii) To convert a pound of water at 100° *C* into steam at 100° *C.*

The second of these is the thermal unit, to which we shall refer hereafter.

CAPACITY FOR HEAT.

52. If a substance (*A*) requires more heat to be applied to it, in order to raise it through a definite range of temperature, than that quantity of heat which will raise an equal weight of a substance (*B*) through the same range, (*A*) is said to have a greater *capacity for heat* than that which (*B*) has.

For example, if we place before a fire, and at equal distances from it, a quantity of water and the same quantity of mercury, each of them contained in equal and similar glass vessels, and each having a thermo-

meter immersed in it, we find that the mercury is warmed by the fire much faster than the water. This shows that mercury has less capacity for heat than water has: it requires a smaller quantity of heat to raise its temperature by the same number of degrees.

53. If we call the quantity of heat that will raise a pound of *water* from 0° *C* to 1° *C* the *unit of heat*, the capacity of another substance for heat will be measured by the number of units of heat that will raise a pound of that substance 1° *C*.

This unit of heat may be called a *Therm*.

54. The thermal unit in France is the quantity of heat required to raise the temperature of *one* kilogramme of water through 1° centigrade. This is called a *calorie*. Roughly speaking, the kilogramme is about $2\frac{1}{5}$ lbs. avoirdupois, and hence 1 calorie = 2·2 English thermal units, or therms.

55. DEF. *The capacity of a body for heat is measured by the number of units of heat required to raise that body one degree of temperature.*

Hence the capacity for heat of 1 pound of water is 1.

SPECIFIC HEAT.

56. The *specific heat* of a substance is equal to the ratio of the quantity of heat, required to raise any weight of that substance 1° *C*, to the quantity of heat required to raise an equal weight of water from 0° *C* to 1° *C*.

For example, to raise the temperature of a pound of charcoal 1° *C* requires one-fourth of the quantity of heat required to raise a pound of water from 0° *C* to 1° *C*. Hence, if the specific heat of water be represented by 1, the specific heat of charcoal will be represented by 0·25. (*See* Appendix III.)

57. The specific heat of a solid increases with an increase of temperature; thus it requires more heat to raise a lump of iron from 20° to 21° than from 19° to 20°. The specific heat of platinum increases much more slowly than that of other metals; indeed, up to 300° *C* it cannot be said to increase at all.

As a solid approaches its melting point, the specific heat increases much more rapidly.

58. The specific heat of liquids usually increases with the temperature.

A substance when liquid has usually a greater specific heat than the same substance in a solid state. Thus the specific heat of ice is only half the specific heat of water.

Water has a higher specific heat than any known solid, and than almost all liquids.

59 In calculations with regard to measures of heat, it is assumed that, if a certain quantity of heat will raise a pound of water through any one degree of temperature, *twice* the quantity will be required to raise *two* pounds of water through the same degree of temperature.

60. The temperature of a body must not be confounded with the quantity of heat that the body contains. If from a kettle of hot water we fill a quart jug and a pint mug, the water in the jug will be at the same temperature as the water in the mug, but the quantity of heat in the jug will be twice as great as the quantity of heat in the mug.

LATENT HEAT.

61. The application of heat to a body may cause a change of state, without causing at the same time a change of temperature.

Thus, when pounded ice is just beginning to melt, its temperature is 0° *C*, and during the whole time of its conversion into water, if the ice and water be stirred, so as to mix them, a thermometer placed in the mixture will mark 0° *C*.

Again, whatever time is employed to heat water from its ordinary temperature of 10° *C* to 100° *C*, the same fire must be applied five times as long to convert it all into steam. Yet all this time a thermometer held in the steam shows only 100° *C*. On the other hand, a pound of water converted into steam, and passed in that form into forty pounds of water, will raise its temperature from 10° *C* to 21° *C*.

62. If water at 94° *C* be mixed with an equal weight of *water* at 0° *C*, the temperature of the mixture is the mean of the two temperatures, that is 47° *C*.

But on mixing water at 94° *C* with an equal weight of *ice* at 0° *C*, Black found that, though the ice melted in a few seconds, the temperature of the mixture was only 12° *C*. This proved that a quantity of heat had been communicated to the ice, with the sole effect of changing its state, without changing its temperature.

In another experiment he suspended in a room, at a temperature of 8·5° *C*, two glass vessels, one containing water at 0°, and the other ice of the same weight at 0°. In half an hour the water had risen 4°, but it took 10½ hours for the ice to melt and rise to 4°.

Hence he inferred that 21 times as much heat was required to raise the ice at 0° to 4° as was required to raise the water from 0° to 4°; and taking as the unit of heat the quantity of heat required to raise the water through a temperature of 1°, 4 units of heat were required to raise the water from 0° to 4°, and (21×4) units or 84 units to raise the ice from 0° to 4°. Now of the 84 units, only 4 units were required to raise the temperature of the ice, when converted into water, from 0° to 4°. Hence it followed that 80 units of heat were absorbed in melting the ice.

63. The heat which enters (or leaves) a body without increasing (or diminishing) the temperature of the body is called *latent heat.* It is called *latent* because the thermometer gives no indication of its entrance or departure.

DEF. *The Latent Heat of a Substance is the quantity of heat which must be communicated to a unit of mass of it in a given state in order to convert it into another state without changing its temperature.*

64. The term *fusion* is applied to the process by which a body passes from the solid to the liquid state.

The term *evaporation* is applied to the process by which a body passes from the liquid to the gaseous state.

65. The measure of the latent heat of fusion of a substance is the number of units of heat absorbed by a unit of mass of the substance in passing from the solid to the liquid state without change of temperature.

66. The measure of the latent heat of evaporation of a substance is the number of units of heat absorbed by a unit of mass of the substance in passing from the liquid to the gaseous state without change of temperature.

67. When we say that the latent heat of ice is 79 thermal units, we mean, that to change a pound of ice at 0° C into water at 0° C requires as much heat as will raise 79 lbs. of water from 0° C to 1° C.

When we say that the latent heat of water at the boiling point is 536 thermal units, we mean, that to convert a pound of water at 100° C into steam at 100° C

requires as much heat as will raise 536 lbs. of water from 0° C to 1° C.

The quantity of heat which is released by the condensation of vapour or freezing of water is exactly equal to that which would be absorbed by the contrary process.

"We must carefully remember that all we know about heat is what occurs when it passes from one body to another, and that we must not assume that, after heat has entered a substance, it exists in the form of heat within that substance."—*Maxwell.*

EXPERIMENTAL METHODS OF MEASURING QUANTITIES OF HEAT.

68. A minute account of the various methods of estimating the quantities of heat that enter or leave bodies, under particular circumstances, is beyond the scope of this treatise. We shall describe briefly a few of the methods.

I. THE METHOD OF MELTING ICE.

69. *A* is a vessel made of thin copper, containing the substance from which the heat is to escape.

B is a larger vessel surrounding *A*, and filled with ice at the melting point.

C is a vessel surrounding *B*, and filled with ice at the melting point.

The ice in *C* prevents any heat from coming from the external air to *B*. Heat passes from the body in *A* into the ice in *B*. Some of this ice is melted, and the body in *A* grows cool, and this process will go on till the body is cooled to the melting point of ice.

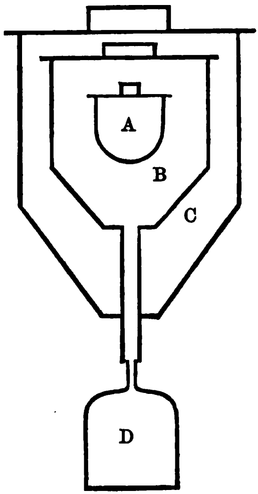

FIG. 11.

The water from the melted ice in *B* runs through an aperture into a vessel *D*, and from the weight of this water we can estimate the amount of heat that has passed out of the body in *A*.

This method is inexact, because some of the water that results from the melted ice remains in the vessel *B*, adhering to the ice.

This instrument is called the *Calorimeter* of Lavoisier and Laplace.

Black's Calorimeter.

70. Black used as a calorimeter a large block of very pure ice, in which a hole was cut, and the opening covered with a thick piece of ice. In the hole he placed the body whose specific heat he had to determine, heated to a certain temperature. When the body had cooled down to 0° *C*, he removed it, and wiped it and the hole dry with a cloth, which had been previously weighed. The increase in the weight of the cloth represented the ice that had been melted.

71. In all questions of the transfer of heat from one body to another by which it is entirely surrounded, or with which it is intimately mixed, it is assumed that the quantity of heat lost by the hotter body is equal to the quantity of heat absorbed by the cooler body.

72. If then W pounds of ice are melted in the calorimeter, since the latent heat of ice is 79, they will represent $79W$ therms given out by the hot body in cooling to 0° *C*.

73. The specific heat of the hot body can then be deduced. For suppose s is its specific heat, w its weight, and $t°$ its temperature at starting, the number of therms given out in cooling through t degrees will be swt; and this being equal to the number of therms absorbed by the ice, we get—

$$swt = 79W$$

$$\text{whence } s = \frac{79W}{wt}$$

Bunsen's Ice-Calorimeter.

74. Water in passing from the solid to the liquid state undergoes a change of volume amounting to very nearly $2\frac{1}{2}$ cubic inches for every pound of ice melted; so that by observing the contraction which a quantity of ice experiences when heat is applied to it, the weight of ice melted can be calculated, and the quantity of heat measured as in the above methods.

The instrument is constructed thus:—A glass tube closed at one end has its lower end hermetically fastened into the top of a glass reservoir containing pure water, from which every trace of air has been expelled by boiling. The lower part of this reservoir contains mercury, and communicates with the outer air by means of a glass tube, bent as is represented in the figure, into the top of which is fitted another tube of finer calibre, graduated into equal known volumes.

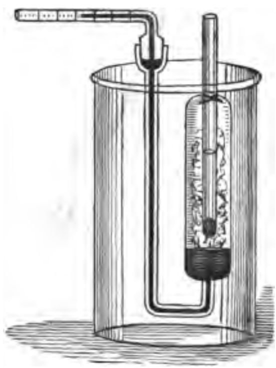

Fig. 12.

To make an experiment, the instrument is first imbedded in freshly fallen snow, and a stream of alcohol, previously cooled by a

freezing mixture considerably below 0° *C*, is introduced by means of a long funnel into the bottom of the open tube. A coating of ice forms round the tube, and the alcohol is then replaced by cold water. After a time, the whole of the reservoir and enclosed tube, with their contents, attain a temperature 0° *C*. The fine tube is then adjusted so that it shall be nearly filled with mercury, and the experimental substance, heated to a known temperature and weighed, is carefully dropped to the bottom of the open tube. Heat then passes from the body to the water which surrounds it, but as water up to 4° *C* is denser than water at 0° *C*, the warmer water remains at the bottom, and transfers its heat through the glass to the ice. The quantity of heat which passes will be proportional to the quantity of ice melted, and can be determined by the contraction of the column of the mercury in the graduated tube. One cubic inch of contraction will then represent very nearly $\frac{2}{5}$ of a pound of ice melted, or 31·6 therms.

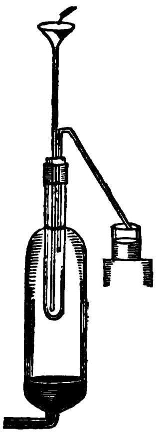

FIG. 13.

More exactly, one pound of ice in melting contracts 2·4192 inches, and therefore 1 cubic inch of contraction represents a weight of 0·41336 of a pound, or 2893·52 grains of ice melted.

II. THE METHOD OF MIXTURE.

75. In this method we estimate the amount of heat that passes *out* of a body, by the increase of temperature in another body, *into* which the heat passes.

A body of known weight and temperature is immersed in water of known weight and temperature. From the temperature of the water, after it and the body have reached a state of equilibrium of temperature, the quantity of heat that has passed out of the body can be estimated.

Let w be the weight of the water, t its initial, and θ its final temperature; then the number of therms absorbed in rising through $\theta - \mathrm{t}$ degrees will be $\mathrm{w}\,(\theta - \mathrm{t})$.

Again let w be the weight of the hot body, t its initial, and θ its final temperature, and s its specific heat, then the number of therms which it gives out in cooling $t - \theta$ degrees will be $sw\,(t - \theta)$,

$$\text{therefore } sw\,(t - \theta) = \mathrm{w}\,(\theta - \mathrm{t})$$

$$\text{and } s = \frac{\mathrm{w}}{w} \cdot \frac{\theta - \mathrm{t}}{t - \theta}$$

(For an account of the method of making this determination, *see* Appendix IV.)

III. THE METHOD OF COOLING.

76. In this method we estimate the amount of heat that passes out of a body at a temperature T, by the *time* in which the body cools down to a temperature t, as compared with the time in which an equal weight of water, under the same external circumstances, cools down from temperature T to temperature t.

EXAMPLES IN CALORIMETRY, SPECIFIC HEAT, AND LATENT HEAT.

77. The units of weight and temperature being 1 lb. and 1° centigrade respectively, the measure of the quantity of heat absorbed by a body whose weight is w lbs. when it is heated through t°, s being the specific heat of the body, is $s\,w\,t$.

Thus, if the specific heat of iron be ·113, 7 lbs. of iron raised from 0° C to 100° C will absorb ·113 × 7 × 100 thermal units. Conversely, 7 lbs. of iron cooled from 100° C to 0° C will lose ·113 × 7 × 100 thermal units.

NOTE.—We here assume, though it is not strictly true, that the capacity for heat of a body remains the same as its temperature rises or falls. (See Art. **62.**)

Ex. 1. A mass of iron, weighing 7 lbs. at the temperature of 100° C, placed on a mass of ice at temperature 0° C, melts a certain quantity of the latter. If the specific heat of iron be ·113 and the latent heat of ice 79 thermal units, calculate the weight of water produced.

·113 × 7 × 100 = number of thermal units given out by the iron. Now x pounds of ice at 0° in melting to x pounds of water at 0° absorb $79x$ thermal units.

∴ if x be the weight required in lbs.

$$79x = \cdot 113 \times 7 \times 100$$

$$\therefore x = \frac{79 \cdot 1}{79} = 1 \cdot 001 \ldots\ldots \text{lbs.}$$

Ex. 2. A mass of iron, weighing 10 lbs. at 100° *C*, is placed in the receiver of a calorimeter, and the water which flows from the apparatus is found to weigh 1·44 lbs. Find the specific heat of iron, the latent heat of fusion of ice being 79.

Let x be the specific heat of iron.

Then $10 \times 100 \times x =$ number of thermal units given out by the iron, and $79 \times 1{\cdot}44 =$ thermal units absorbed by the melted ice.

$$\therefore 10 \times 100 \times x = 79 \times 1{\cdot}44.$$
$$\therefore 1000x = 113{\cdot}76.$$
$$\therefore x = {\cdot}11376.$$

Ex. 3. A pound of platinum is placed in a furnace, and, having acquired the temperature of the furnace, is plunged into a vessel containing 10 lbs. of water at 10° *C*. The temperature of the water rises to 14·3° *C*; what is the temperature of the furnace?

Let t° *C* be the temperature of the furnace.

Then the pound of platinum loses $(t - 14{\cdot}3)$ degrees of temperature, and therefore parts with $(t - 14{\cdot}3) \times {\cdot}032$ thermal units; and the 10 lbs. of water gain 4·3 degrees of temperature, and therefore absorb $4{\cdot}3 \times 10$ thermal units.

$$\text{Hence } (t - 14{\cdot}3) \times {\cdot}032 = 4{\cdot}3 \times 10.$$
$$\text{or, } {\cdot}032t - {\cdot}4576 = 43.$$
$$\therefore t = \frac{43{\cdot}4576}{{\cdot}032} = 1355{\cdot}05.$$

Ex. 4. 10 lbs. of iron at 100° C were immersed in 18 lbs. of water at 15° C, and the resulting temperature was observed to be 20° C. Determine from this the specific heat of iron.

Let s be the specific heat of iron.

Then 10 lbs. of iron part with $80 \times 10 \times s$ thermal units, and 18 lbs. of water absorb 18×5 thermal units.

$$\therefore 80 \times 10 \times s = 18 \times 5.$$

$$\therefore s = \frac{90}{800} = \cdot 1125.$$

EXAMPLES FOR PRACTICE.

(1.) If 6 lbs. of water at 35° C be mixed with 5 lbs. of water at 67° C, find the temperature of the mixture.

(2.) If 5 lbs. of mercury at 25° C be mixed with 12 lbs. of mercury at 45° C, find the temperature of the mixture.

(3.) How many units of heat are required to raise 40 lbs. of iron from 15° C to 45° C? The specific heat of iron is ·1125.

(4.) How many units of heat are required to raise 12 lbs. of mercury from 5° C to 35° C? The specific heat of mercury is ·033.

(5.) Three lbs. of mercury at 90° C are mixed with 2 lbs. of water at 25° C; find the temperature of the mixture. The specific heat of mercury is ·033.

(6.) The specific heat of ice is ·5. How many units of heat must be applied to 10 lbs. of ice, which has a temperature of −5° C, to raise its temperature, without melting, to 0° C?

(7.) How many thermal units will be required to raise 4 lbs. of brass from 46° C to 75° C? The specific heat of brass is ·094.

(8.) Twelve lbs. of mercury at 15° C are mixed with 6 lbs. of iron filings at 50° C; find the temperature of the mixture. The specific heat of mercury is ·033, and that of iron filings is ·113.

(9.) The specific heat of mercury being ·032, how much mercury at the temperature of 120° C will raise the temperature of 10 lbs. of water from 30° to 40° C?

(10.) Ten lbs. of tin at 0° C are placed in 1 lb. of water at 78° C: the resulting temperature is 50° C; find the specific heat of tin.

(11.) How much coal is wanted to heat 40 tons of iron 1000° C, supposing a pound of coal in burning to give out 8000 units of heat, and the specific heat of iron to be ·11379?

(12.) Two hundred ozs. of platinum are heated in a furnace to 1080° C, and are then placed in 1000 ozs. of water at 13° C: the temperature of the water rises to 20° C; find the specific heat of platinum.

(13.) A piece of iron weighing 80 ozs., and at a temperature of 100° C, is immersed in 132 ozs. of water at a temperature of 40° C: after the temperature has become uniform, that of the cooling water is found to be 43·75° C; what is the specific heat of the iron?

NOTE. In the questions that follow, except those in which any other statement is made, the latent heat of

ice at 0° *C* is taken as 79 thermal units, and the latent heat of steam at 100° *C* is taken as 536 thermal units.

(14.) How many thermal units will be required to convert 10 lbs. of ice at 0° *C* into water at 20° *C*?

(15.) How many thermal units will be required to convert 20 lbs. of water at 60° *C* into steam at 100° *C*?

(16.) What quantity of heat will be required to convert 30 lbs. of water at 0° *C* into steam at 100° *C*?

(17.) Trace the changes of volume experienced by a pound of ice as it is gradually heated under normal atmospheric pressure from −20° *C* to 120° *C*.

(18.) Calculate the number of thermal units employed in raising 100 lbs. of ice from −10° *C* to steam at 100° *C*, the specific heat of ice being ·5.

(19.) The specific heat of ice being ·5, calculate the number of units of heat expended in raising 10 lbs. of ice from −10° *C* to 20° *C*.

(20.) A mass of platinum weighing 25 lbs. at the temperature of 100° *C*, placed in a mass of ice at the temperature of 0° *C*, melts a certain quantity of the latter. If the specific heat of platinum be ·032, calculate the weight of water produced.

(21.) How many pounds of steam at 100° *C* will just melt 12 lbs. of ice at 0° *C*?

(22.) The steam from 10 lbs. of water is conducted into a vessel containing 120 lbs. of water at 0° *C*; find the resulting temperature.

(23.) The steam from 1 lb. of water is condensed in

5·36 lbs. of water at 0° C; what is the temperature of the mixture?

(24.) A pound of steam at 100° C is mixed with 10 lbs. of water at 20° C; what is the resulting temperature?

(25.) The specific heat of ice is ·504. The air and everything else in a certain room is at 0° C, and a pound of ice at − 10° C is then placed in a vessel in the room, and water at 12° C is slowly poured upon it. It is found that 7·045 lbs. of this water are required to just melt the ice. Find the latent heat of the fusion of ice.

(26.) $1\frac{1}{8}$ lb. of ice at 0° C is dropped into 1 lb. of boiling water; find the resulting temperature of the mixture.

(27.) In a Bunsen's ice calorimeter, the degrees being $\frac{1}{10}$ of an inch long, and the diameter of the tube being 0·0465 of an inch; if when a specimen of silver weighing 150 grains is heated to 99·8° C and dropped into the water, the mercury column retreats through 21·5 degrees; calculate the specific heat of silver.

(Volume of a cylinder $= \frac{\pi d^2 l}{4}$.)

SECTION VII.

DIFFUSION OF HEAT.

78. Heat can be transferred from one body to another in several ways, three of which—Radiation, Convection, Conduction—we now proceed to describe.

I. RADIATION.

79. The process by which heat is transmitted *across an intervening space* from one body to another is called *Radiation.*

80. Radiation and Radiant Heat conform to the same laws as Light; thus:—

(*a*) Radiant heat can pass through a medium without warming it in any appreciable degree.

(*b*) Rays of heat, like rays of light, travel in straight lines through a uniform medium.

(*c*) The heat rays traverse the space between the bodies with very great rapidity.

"Radiant heat is the same thing as what is called light, only perceived by us through a different channel. The same radiation, which, when we become aware of it by the eye, we call light, when we detect it by a thermometer, or by the sensation of heat, we call radiant heat."—*Maxwell.*

81. Our chief supply of heat, received by the earth from the sun, reaches us by the process of radiation.

When we stand before a fire the warmth we feel is caused chiefly by radiation, because air is a bad conductor.

82. No known body allows heat-rays to pass through it without absorbing a portion of the heat. Substances which do not absorb much of the heat are called Diathermanous, and such as absorb much of it, or do not allow it to pass at all, are called Athermanous. Some colourless gases are diathermanous to a high

degree. A substance may be transparent and yet not diathermanous. Hence the use of a glass screen before a bright fire. Plate glass is more diathermanous than common glass, the former allowing 65, the latter 52 parts out of 100 of the heat to pass.

The solid possessing the highest diathermancy is rock-salt, which allows 92 parts out of 100 to pass.

Lamp-black (which is the same substance as finely-divided charcoal) is a great absorbent of heat, and a sheet of paper coated with lamp-black is almost completely athermanous.

83. The radiation from a luminous source consists partly of visible rays, which we call rays of light, but chiefly of invisible rays, which are called rays of heat. Nine parts out of ten of the radiation from an oil flame consist of rays of heat.

Glass is diathermanous for rays of light, but athermanous for rays of heat. The rays of light that radiate from the sun pass readily through the glass of a green-house, and engender heat in the earth and other objects within the greenhouse; these objects radiate heat in the form of rays of heat, which cannot pass through the glass. Thus a store of heat is accumulated in the green-house.

84. When radiant heat falls on a surface of polished metal, it is reflected just in the same way as rays of light. If at the point of incidence a normal be drawn to the reflecting surface, the lines of incidence and reflection are in the same plane with the normal, and make equal angles with it.

Hence it is that, by exposing a concave surface of polished metal to the action of the rays of heat coming from a fire, the reflected rays may be concentrated in a focus, and their heat directed to an object between the reflecting surface and the fire.

This is the result obtained by the use of the Dutch oven, the plate-warmer, and the meat-screen or reflector.

"Polished silver reflects nearly the whole of the radiation that falls on it, absorbing only about a fortieth part and transmitting none."—*Maxwell.*

The disturbing effects of radiation on the thermometer are greatly lessened by covering the bulb with polished silver.

85. Good reflectors are bad radiators and bad absorbers.

"Vessels that are intended to retain their heat should be metallic and highly polished. Steam or air pipes for warming houses should be polished in those parts where the heat is not required to be communicated, and covered with some radiating substance, as lamp-black or plumbago, in those rooms which are to be heated by them. Culinary implements should be blackened, and not polished, on those parts which are to receive heat. The heated surface of fireplaces or stoves should not be metallic, but of earthy or stony materials, and in this case much more heat will be communicated by radiation."—*Sir H. Davy.*

Good absorbers are good radiators.

86. Perfectly dry air seems to be nearly incapable of absorbing radiant heat. In Greenland, a country covered with ice and snow, the pitch has been seen to melt on the side of a ship exposed to the direct rays of the sun, while at the same time the surrounding air was far below the freezing point. The air is cooled by contact with the snow, but it is not heated by the radiation from the sun.

87. Heat in its radiant state does not raise the temperature of the media which it traverses. A tube full of ether may be held in the focus of a burning mirror without becoming sensibly hotter; but the moment that the absorption of the rays is caused in any way, as by introducing a bit of charcoal into the liquid, the ether begins to boil.

88. Many gases which are transparent to light are very opaque to heat rays. Olefiant gas is an instance of this, and Tyndall has found besides that scents render the air in which they are diffused extremely athermanous. The transparent vapour of water in the air is opaque to heat rays, which acts therefore, as regards the atmosphere, like the glass of a greenhouse, preventing the heat radiated from the ground from escaping, and raising the temperature of the atmosphere.

NEWTON'S LAW OF COOLING.

89. Newton laid down the following law in reference to cooling by radiation :—

The quantity of heat passing from a body, in equal

intervals of time, is in proportion to the excess of its temperature above that of the surrounding medium.

Hence if a body, at a temperature of 100° C, in an atmosphere of 0° C, loses 10° in a minute, the same body, when heated to 50° C, would lose 5° in a minute in an atmosphere of 0° C.

This law has been shown not to be of general application, but it is very nearly true when the difference of temperature does not exceed two or three degrees.

II. CONVECTION.

90. Convection of heat is the process by which heat is transferred from one place to another by means of the motion of a body, generally a fluid, carrying heat with it.

91. When a kettle filled with water is placed on the fire, heat is communicated to the water at the bottom by conduction. This water is rarefied, and the pressure of the heavier water above, and on all sides of it, forces it up in a current, ascending in the middle of the kettle, while the colder water runs in currents, descending by the sides. This process goes on continuously, the colder water always sinking to the bottom of the kettle, receiving heat, and then expanding and ascending to convey heat through the whole body of water. These currents are called convection currents. If anything occurs to check the free circulation of a liquid, such as milk, which is being heated by this process, the layers nearest to the bottom receive too

much heat, and the milk is "burnt;" and to prevent this, we must assist the circulation by stirring the liquid occasionally.

92. The process of convection of heat is applied to the warming of buildings by hot water or hot air. If a pipe be inserted near the top of a boiler in the basement of a house, and be carried up in any direction, and to any height, returning ultimately to the bottom of the boiler; if the boiler and pipe be then filled with water, and heat be applied to the bottom of the boiler, the current of heated water will constantly ascend through the pipe at the top of the boiler, while water at a lower temperature will be constantly flowing into the boiler through the pipe at the bottom.

93. When a fire is lighted in a grate, there is above it a body of air in the chimney at the same temperature as the outer air. The heat derived by conduction from the fire expands the air at the lower part of the chimney, and then by the process of convection of heat a current of warm air ascends the chimney. If the room were completely closed against the entrance of cold air by some other opening, the cold air would come down from the top of the chimney, beating down the smoke into the room. Hence the necessity for letting in fresh air to the room by door or window or some other opening.

94. In a room that has been much heated by respiration or the burning of lights, especially gas, the air

near the ceiling becomes much higher in temperature than that in the lower parts of the room. Hence the necessity for making an outlet for this heated air near the ceiling, and for supplying its place by fresh air admitted near the floor.

III. CONDUCTION.

95. The process by which heat passes from hotter to colder parts of a body, or from one body to another in contact with it, is called the conduction of heat.

Heat flows more quickly through some substances than through others. The substances through which it flows with greater facility are called *better conductors.*

96. The first effect of a flow of heat is to raise the temperature of those parts into which the flow takes place, and, if no heat is allowed to escape from the body or system, in course of time the whole will attain the same temperature, and the flow will stop.

97. If, however, heat is withdrawn, or permitted to escape from the body in which the flow of heat occurs, after a time the temperatures of the several parts cease to rise, and a permanent state is reached in which the temperature of every point is fixed, those points having a higher temperature which are nearer to the source of heat or farther from the place where the heat is ultimately withdrawn.

Under these circumstances the flow of heat is said to be *steady.*

SPECIFIC THERMAL CONDUCTIVITY OF A SUBSTANCE.

98. The conductivity of a body is measured by the number of units of heat that will flow in a second across a cube of the material, whose volume is one inch, and whose opposite surfaces differ in temperature by 1° *C.*

99. Take an inch as the unit of length, and a second as the unit of time. Suppose the temperature of the inner surface of the flat bottom of an iron steam boiler to be 1° *C* less than the temperature of the outer surface; then if under a steady flow of heat c units of heat flow through each cubic inch of the metal in a second, c is called the specific thermal conductivity of the metal.

100. When a bar of dry material is heated at one end, a good deal of heat is carried off by radiation and by convection of air from its surfaces, and, if the bar is long enough, ultimately the whole of the heat which enters from the source is carried off in this manner. So that if any cross section of a bar be considered, the heat which is conducted across it is equal to the heat lost by radiation and convection beyond it, and by measuring the latter we can determine the former. (*See* Appendix V.)

101. All metals are far better conductors than wood or stone or ivory.

The following are arranged in order of conducting power:—

Silver,	100
Copper,	77·6
Gold,	53·2
Zinc,	19·9
Tin,	14·5
Steel,	12
Iron,	11·9
Lead,	8·5
Platinum,	8·2

The brass handle of a door feels much colder or hotter than a panel of the door, though both are at the same temperature, because the metal draws away or imparts heat, according as its temperature is below or above that of the hand, more quickly than the wood.

The wooden kettle-holder protects the hand from the heat of the metal; and pieces of ivory are inserted between the handle and body of a silver teapot, because ivory is a slow conductor of heat.

A rod of iron or copper, if one end of it be put in the fire and made red-hot, transmits the heat so quickly and in such quantity to the other end that it cannot be touched without burning the hand; while a stick of wood of the same size can easily be held by the one end while the other is blazing.

Again, you may hold with your fingers one end of a platinum wire, two inches long, while the other end is

heated to a white heat by the blowpipe flame; but if you tried the same experiment with a copper wire your fingers would be burnt.

102. The great conductivity of metals is turned to use in the *Safety Lamp.* A piece of wire gauze, placed over a jet of lighted gas, does not allow the flame to pass through it. If the gas be allowed to pass through the wire gauze, and then be lighted above, the flame burns on without reaching the jet. The cause of this is, that the heat of the flame is rapidly conducted away along the metal, so that there is not heat enough left at the point of contact to ignite the gas on the other side.

Sir Humphry Davy invented the safety-lamp, which is a lamp surrounded with wire gauze. The explosive gases pass through this gauze, and burn inside the lamp, so as to warn the miner of their approach; but the flame has no power to ignite them outside the lamp.

103. The conductivity of a body for heat must not be confounded with the rate at which a bar of the substance rises in temperature, which depends on its specific heat as well.

For example, if a bar of iron and a bar of bismuth of equal dimensions are coated with wax, and one end of each exposed to the same source of heat; and if after two minutes the wax is found to be melted for 3 inches along the bismuth bar, and for 2½ inches along

the iron bar, we must not conclude that bismuth is a better conductor than iron. We have to take into account the fact that the specific heat of iron is very much greater than that of bismuth, and that consequently the temperature of the bar of bismuth increases much more rapidly than that of the bar of iron. The results of experiments show that if the specific heat of water be represented by 1, the specific heats of iron and bismuth are represented by ·11 and ·03; and if the conductivity of silver be represented by 100, the conductivities of iron and bismuth are represented by 11·9 and 1·8.

104. Sand is a slow conductor. Masses of red-hot iron may be safely carried in wooden barrows filled with sand.

105. Wool is a slow conductor. A blanket put round a lump of ice in an ice-box preserves it from melting for a long time.

The usual construction of fire-proof safes is to put an iron box into one considerably larger, and to fill up the space between them with some slow-conducting substance, such as felt.

106. The small conductivity of felt is turned to use in the *Norwegian stove*. A wooden box is lined thickly with felt, room being left in the centre for a stew-pan. The contents of the stew-pan are raised to the boiling temperature, and then the pan is put in the box, and covered over with a felt top. The cooking then goes

on without any fire; for the temperature of the pan does not sink more than 1° *C* in every fifteen minutes.

107. On a winter's morning a piece of oilcloth feels much colder than a carpet, though both are at the same temperature, because the oilcloth, being a much better conductor than the carpet, conducts the heat from the hand much more rapidly.

On the other hand, in a room heated to 130° *C*, the oilcloth feels much hotter than the carpet, because the heat passes much more quickly to the hand from the oilcloth.

108. Bricks and straw are slow conductors: hence an ice-house is generally made of bricks, and straw is placed as a covering on the ice.

Stone is a better conductor than either brick or wood; hence houses in cold countries are usually built with bricks or wood; while stone is a more suitable material for hot climates.

109. Animal and vegetable substances are, in general, very slow conductors: thus the hair and the wool of animals, and the feathers of birds, protect them from the cold, and by enclosing and retaining air, which is a still slower conductor, they increase the protection.

110. Fluids (mercury is an exception) conduct heat slowly, and gaseous fluids very slowly.

"The heat of metals at the temperature of 120° *F* is scarcely supportable; water scalds at 150°, but air

may be heated to 240° without being painful to our organs of sensation.

"Again, in the high northern latitudes a cold has been experienced, without injury, in which mercury froze; and if, in this state of the atmosphere, metallic substances, of the same temperature, were touched, a sensation like that of burning was experienced, and the part blistered."—*Sir H. Davy.*

111. Instances of the slow conduction of air are—Double windows, through which the warmth of a room escapes very slowly, because it has to pass through the air confined between the windows; and loose gloves, which are warmer in winter than tight-fitting gloves.

Ex. How many units of heat will pass in an hour through each square foot of the surface of an iron boiler, the temperature of the inner surface being 140° *C*, and that of the outer surface 110° *C*, the specific thermal conductivity of iron being ·0011, and the thickness of the boiler being ½ an inch?

Number of units of heat

$$=(60\times 60)\times(12\times 12\times 2)\times(140-110)\times{\cdot}0011$$
$$=3600\times 288\times 30\times{\cdot}0011.$$
$$=36\times 288\times 3\times 1{\cdot}1$$
$$=34214{\cdot}4.$$

EXAMPLES FOR PRACTICE.

(1.) Taking the value of the specific conductivity of n as 0·0011, determine the value for silver. (Use 101.)

(2.) How much heat is conducted through each square inch of ground in the course of a year, if the temperature increases 1° *C* for every 120 feet of descent? The mean specific conductivity of the earth's crust being taken as 0·00002.

(3.) Determine as above, from Art. 101, the conductivity of copper, and thence deduce the number of therms passing per hour from the surface of a copper boiler $\frac{3}{8}$ of an inch thick, exposing an area of 10 square feet, if the inner surface be maintained at a temperature of 100° *C*, and the outer surface be half a degree lower.

(4.) Calculate the weight of water at 100° *C* which the heat lost in the preceding example would have converted into steam in the same time.

SECTION VIII.

FORMATION OF VAPOUR, DEW, ETC.

112. When a liquid (or solid) is passing into the gaseous state, the process is called *Evaporation.* When a vapour is returning to the liquid (or solid) state, the process is called *Condensation.*

113. When a liquid has its surface exposed, it evaporates until the whole of the surrounding space is filled with vapour of a certain density or pressure depending upon the temperature and the nature of the liquid. When this condition is reached, evaporation stops, and the space is said to be saturated with the

gas or vapour. The gas then has its *maximum pressure* for that temperature.

114. If the temperature is raised, more gas will be formed, but if the temperature is lowered, some of the gas will be reconverted into the liquid form, until it reaches the lower pressure, which corresponds to the diminished temperature.

115. This state of things is unaffected by the presence of other gases or vapours in the space, except that the evaporation will take place more slowly; so that in the one case the change of temperature and the change of gas-pressure will take place simultaneously or nearly so, while in the other, the temperature will be able to rise much more rapidly than the pressure.

The total pressure, then, of a gas and vapour in any space is equal to the sum of the pressures due to each separately.

116. "A vapour which is at the greatest density and pressure corresponding to its temperature is called a *saturated vapour*. It is then just at the point of condensation, and the slightest increase of pressure, or decrease of temperature, will cause some of the vapour to be condensed."—*Maxwell.*

117. Some solid bodies are constantly in a state of evaporation. Solid camphor is constantly emitting vapour, which is condensed and adheres, like ice-particles, to the top and sides of the vessel containing it.

Ice is constantly evaporating: patches of snow gradually waste and disappear, even during a severe frost.

118. The circumstance mentioned above in Art. 115, viz.:—that in a mixed atmosphere the temperature is able to rise faster than the corresponding pressure of vapour in consequence of the slowness of evaporation, causes the pressure of vapour in the air to be often less than it should be, and to correspond with some lower temperature.

119. This lower temperature is called the *dew-point*, and it is the temperature at which, if the atmosphere is cooled down, the vapour in it begins to condense.

To determine the dew-point, a vessel is cooled till dew begins to be deposited on it, and its temperature (τ) is observed; again its temperature is allowed to rise, and the point (t) is observed when the dew has just disappeared. Then $\frac{1}{2}(\tau + t)$ is taken to be the dew-point. (For further particulars *see* Appendix VI.)

120. An instrument for determining the dew-point is called a *dew-point hygrometer*.

121. *Daniell's Hygrometer* consists of a glass tube, bent twice at right angles, and terminating at each end in a bulb. In the longer limb of the tube is enclosed a delicate thermometer, descending to the centre of the bulb, which is about three parts filled with sulphuric ether. All the other parts of the tube are freed from air, so that they are occupied by the vapour of the ether. The bulb containing the ether is made of black

glass; the other bulb is transparent, and covered with muslin. Ether is poured gradually on the muslin.

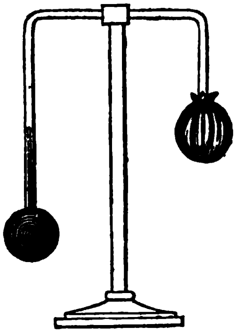

FIG. 14.

The rapid evaporation of this ether cools the bulb and causes condensation of the ethereal vapour in its interior. This causes the ether in the black bulb to evaporate, whereby its temperature is greatly reduced. The vapour in the air round this bulb is deprived of its warmth, and is soon cooled to the temperature at which its pressure is the maximum. Directly it falls below this temperature dew will be deposited on the black bulb. The reading (τ) of the thermometer in the bulb is then taken; and a second reading (t) immediately after the dew has disappeared while the instrument is recovering its temperature. Then $\frac{1}{2}(\tau + t)$ is the dew point.

122. There are many objections to this form of instrument. Regnault has however succeeded in modifying it in such a way as to obviate them all.

The bulb in *Regnault's Hygrometer* is of highly polished silver, and the ether contained in it is caused to evaporate by a current of air drawn through it by means of an aspirator. The thermometer too is very much longer and more delicate. (*See* Fig. 14.)

By these means, the temperature of the air in contact with the bulb is correctly indicated by the thermometer, and there is no evaporation of ether outside the hygrometer. If necessary also the observer can operate at a distance from the instrument, the thermometer being read through a telescope, and thus any errors which the neighbourhood of his own body, by constantly exhaling moisture, would tend to cause are avoided.

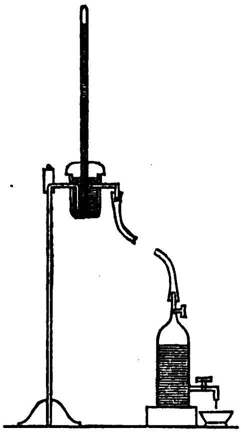

Fig. 15.

123. Another instrument for finding the dew-point is the *wet and dry bulb hygrometer*. This instrument consists of two thermometers, mounted on the same bracket, one marked *dry*, the other *wet*. The bulb of the wet thermometer is covered with muslin, and just above the bulb is twisted a conducting thread of lamp-wick, which passes into a vessel of water fixed to the bracket. This thread keeps the muslin constantly moist. The moisture from the muslin is constantly evaporating, and as evaporation is always accompanied by cooling, the wet bulb thermometer falls, and the drier the air is, the greater will be the difference between the two thermometers. From the difference between the readings of the thermometers, with the aid of

tables constructed for the purpose, the dew-point can be ascertained.

THE FORMATION OF DEW, MIST, CLOUDS, RAIN, HAIL, AND SNOW.

124. The true explanation of the formation of dew was first given by Mr. Wells, a London physician, in 1814. It had been observed that a thermometer, placed on grass in the open air, when dew was being formed, indicated a temperature several degrees lower than that marked by a thermometer suspended two feet above the grass. It was supposed that the formation of dew was *the cause* of the increase of cold. Mr. Wells, by a series of experiments, proved that dew is the *effect* of chilling by radiation.

125. Dew appears in an open grass field, during a still and bright night, from the following causes. The *upper* parts of the grass radiate their heat into the regions above, which send back no heat in return; the *lower* parts of the grass, from the smallness of their conducting power, transmit but little of the earth's heat to the upper parts. The grass being colder than the atmosphere, receives heat from the atmosphere, which consequently becomes colder; and if its temperature be sufficiently decreased, the vapour in it becomes cooled below the point at which its pressure can be maintained, and some of it is therefore condensed into dew and deposited on the grass.

126. Dew appears chiefly where it is most wanted, on herbage and low plants, avoiding, in a great measure, rocks, bare earth, and water.

127. When dew is deposited on bodies cooled below the freezing point, it is solidified into hoar-frost and rime.

128. A solid body between a substance on the ground and the sky, prevents the substance from becoming cold by radiation, sending back to the substance the heat received from it. A very slight covering protects a plant from frost.

129. Dew is formed more freely on a *clear* night, because clouds radiate back the heat intercepted by them in its progress from the earth upwards.

130. Dew is formed more freely on a *calm* night, because any agitation of the atmosphere tends to send continually currents of warmer air, which will replace the heat that substances lose by radiation.

131. Grass, on a clear and calm night, is much colder than the gravel or earth by its side, because heat is conducted better to the latter from the earth below, and also because grass radiates its heat faster than gravel, on account of the larger amount of surface which is exposed.

132. Air, on a clear and calm night, is colder at the surface of an open plain than at any point above the surface for at least 200 feet; and frosts are less severe

on hills of moderate height than on the neighbouring plains, when the night is still and the sky unclouded.

133. The leaves of trees often remain dry, while grass near the trees is covered with dew. This may be because more air is stirring about the tree, and because but few of the leaves are exposed to the sky above, and because the air about the tree is warmer than that close to the grass.

134. "Bright metals, exposed to a clear sky, in a calm night, will be less dewed on their upper surface than other solid bodies, since of all bodies they will, in such a situation, lose the smallest quantity of heat by radiation, at the same time that they are capable of receiving by conduction at least as much heat as any others from the atmosphere, and more than any others from the solid substances which they happen to touch."—*Wells.*

135. "Painted bodies radiate very fast. If part of a wooden pole be painted, and part not, the painted part, exposed in a clear night, will become considerably colder than the unpainted part, and in the morning dew will be found standing thick on the one, while there is little or none on the unpainted part."—*Herapath.*

136. Ice is obtained in hot parts of India by means of radiation.

"Square holes, 30 feet wide and 2 feet deep, are dug in a large plain; the bottoms of the holes are covered for 8 inches thick with dry stems of Indian corn. On this are placed small unglazed earthen pans, 1 inch

thick and $1\frac{1}{4}$ inch deep, filled with boiled soft water. If the night is calm and clear, they never fail to obtain ice, though the temperature of the air all through the night should never descend below 40° Fahr."—*Sir R. Baker.*

137. The dissemination of vapour through the air is very much assisted by the convection currents caused by the warming of the air which is in contact with the ground. In this way it may be carried up into the upper regions of the atmosphere, where it will remain so long as its temperature is maintained above its dew-point.

138. The temperature of a mass of air and of its contained vapour may be lowered in the following ways :—

(*a*) By mixing with colder air.
(*b*) By contact with colder surfaces, such as moun tain tops.
(*c*) By radiation into space.
(*d*) By expansion owing to reduced pressure.

These four causes, operating together or singly, may produce condensation of vapour from the atmosphere.

139. From a moist and warm soil vapour rises, spreads itself into the colder air, and is condensed into small aqueous particles, which float in the air, and become visible as *Mist* or *Fog*.

140. *Clouds* are formed from the condensed vapours

rising from the earth, and differ from mist only in occupying higher regions of the atmosphere.

It has been shown that, supposing the clouds or mist to be composed of excessively small particles, the rate at which such particles would fall or move through the air is so slow that they partake as a whole of the same motions as the mass of the air in which they may be, and in this way they become as it were suspended or buoyed up in the atmosphere.

When this watery vapour becomes more condensed, the particles unite and fall as *rain*.

141. *Snow* is vapour suddenly condensed into the solid state.

142. *Hail* is formed out of rain-drops, that freeze as they fall through colder regions.

The small cloud particles are formed into rain-drops or hail-stones in consequence of the larger particles descending faster than the others, combining with those which they overtake in their descent, and thus having their velocity increased, and adding to their size at an increasing rate.

143. Mountains stop the currents of warm and moist air rising from the earth, and in part condense them, in part force them upwards to regions where, owing to the reduced pressure, they are condensed and remain as mist, or fall as rain or snow.

144. The south wind is moist and warm, and mixing with the colder air of northern regions results in clouds and rain.

145. The wind that causes most rain in England is the south-west, and hence the eastern counties have the smallest rain-fall, because the rain-wind has to cross the island before it reaches them.

146. When the temperature of a portion of the earth's surface becomes higher, the air in contact with that surface is heated, expands, and rises, while its place is filled by colder air from lateral directions.

This is the cause of the *Land and Sea Breezes*, that blow regularly in hot countries near the coast—from the sea to the land during the day, and from the land to the sea at night. For, during the day, the land is more heated than the sea, and the air that lies over the land is forced upwards by colder and therefore heavier air coming from the sea; but during the night the land cools faster than the sea, and the contrary effect is produced.

THE TRADE WINDS.

147. The air about the equator is heated, expands, and rises, its place being supplied by air moving towards the equator from the poles. Hence there is a constant current of air above setting from the equator, and a constant current below setting towards the equator. The lower current forms what are called the *Trade Winds*, which are felt for 30° of latitude on each side of the equator. If the earth were at rest, these winds would set due north and south; but

as the earth's surface, revolving from west to east, has its greatest velocity at the equator, and this velocity gradually decreases from the equator to the poles, the currents from the north and south are constantly acquiring a motion from east to west relative to the place over which they are passing; and this motion, combined with their original motion from north to south and from south to north, produces a permanent north-easterly current in the northern hemisphere, and a south-easterly current in the southern hemisphere.

148. The mists on low-lying marsh lands in the evening are caused by the rapid cooling of the air when the sun has set.

The morning mists over rivers and lakes are caused by the water cooling much more slowly than the air that is in contact with it.

149. In hot dry weather there is often more vapour in the atmosphere than in cold wet weather.

EBULLITION.

150. By the word *Ebullition*, or boiling, we mean the formation in any liquid of bubbles of vapour, whose internal pressure is just equal to the external pressure upon them.

151. The process of ebullition may be seen by heating water from below in a glass vessel. At first, when the water has become heated throughout, bubbles of

the air which the water contained within it, form, rise and burst without any sound. Next, when the water at the bottom of the vessel is heated to the boiling point, bubbles of vapour are formed there; these bubbles struggle up into the colder water above, and are condensed and collapse with a noise, which we call *simmering* or *singing*. When the temperature of the whole mass of liquid becomes nearly uniform, the bubbles of steam, as they are formed, rise to the surface, burst under the pressure of the atmosphere, and cast forth invisible steam.

NOTE.—That, which we call steam, issuing from the spout of a kettle of boiling water, is partly *condensed steam*, which is therefore visible, and partly *uncondensed steam*, which is invisible.

152. The temperature of ebullition increases with the pressure. If the pressure at the surface of a liquid, just beginning to boil, be increased, ebullition is checked, because the vapour bubbles cannot form at the surface under the increased pressure.

On the other hand, if the pressure at the surface of a liquid, which has just ceased to boil, be decreased, ebullition will commence again. For example: fill a glass flask half full of water, make it boil over a spirit-lamp, then cork it up, and when ebullition has ceased, dash some cold water on the top of the flask. The application of the cold water condenses the steam, lessens the pressure on the surface of the water, and makes it boil again.

153. The atmosphere is most dense at the surface of the earth, and its density diminishes with its height. Hence, as one ascends a mountain, the weight of the incumbent air is diminished, and water boils at a lower temperature. At the top of Mont Blanc (15,600 feet) water boils at 85° *C.*

Roughly speaking, an ascent of 1080 feet produces a diminution of 1° *C* in the boiling point.

Hence arise the difficulties in cooking tea and other food on the top of a high mountain, because it is impossible at a great altitude, unless the water be enclosed in a vessel with a tight-fitting lid, to heat it up to the temperature of 100° *C*, the ordinary boiling point.

154. As soon as ebullition commences, the temperature of the vapour, rising from the free surface of the liquid, is invariable, and continues so till all the liquid has been converted into vapour.

The temperature of the liquid increases slightly, while ebullition is going on, and it is greater at the bottom of the vessel than at the top; yet still it is not so much above the boiling point as to prevent it from keeping the vessel from burning. Thus vessels of tin, copper, or any other metal, may be exposed to the action of a very hot fire without fear of injury to them, if they contain water or some liquid, which, by its contact, will keep them from burning. (*See* Appendix VII.)

PAPIN'S DIGESTER.

155. Papin's digester is a copper vessel, having a lid nicely fitted to it and kept fast by screws. If this vessel be half filled with water, and the lid screwed down tight, and if it be then set over a brisk fire, a portion of the water is soon converted into steam. The steam, being unable to escape, presses on the surface of the water, and prevents the conversion of any more water into steam, till the temperature of the water is raised *above the boiling point.* By the confinement of the steam thus produced, and the regular increase of the pressure on the surface of the water, the contents of the digester may be raised to a very high temperature. By this means, substances such as horn, cartilage, and bone, can be easily reduced to a jelly. A heat has been produced in the digester sufficient even for melting bits of tin and lead suspended by wires in the midst of the vessel.

THE SPHEROIDAL CONDITION.

156. If we drop water on a warm surface it rapidly evaporates without noise: if the surface be nearly red-hot the water instantly and noisily hisses into steam. But if the surface be intensely hot the water rolls about on the glowing surface in liquid drops. This is called the *Spheroidal Condition,* from the shape assumed by the drops.

Two explanations of this phenomenon are given :—

(i) That the drop is sustained on a cushion of vapour suddenly generated by the contact of the liquid with the hot surface.

(ii) That the molecules thrown off with great rapidity from the hot surface, bombard the cold surface of the drop, and thus keep it away from the hot surface.

It has been proved that the liquid drop does not touch the hot surface.

157. If a gas be subjected to a very gradually increasing temperature, and at the same time the pressure be adjusted so as to keep the gas at its maximum density, after a time a point will be reached, above which apparently no amount of pressure will produce condensation, the gas being permanent.

This point is called the *critical temperature* of the gas, and differs very much in different gases.

For carbonic acid gas it is about	31° *C*
For carbon disulphide ,, ,,	262° *C*
For water ,, ,,	773° *C*
For oxygen and nitrogen (Air) below	– 90° *C*.

158. When a substance is heated nearly to its critical temperature and at the same time subjected to pressure sufficient to keep it partly or wholly liquid, the distinctive difference between the gaseous and the liquid states becomes less and less obvious, until it becomes possible to convert it from one into the other without apparent abrupt change taking place.

159. It is probable that gases only obey Boyle's law strictly when at temperatures considerably above their critical points.

SECTION IX.

CONGELATION.

160. The process by which water is converted into ice is called *Congelation.*

The following is an explanation of the process by which ice is formed on a sheet of water in a calm frosty night. The water at the surface is first chilled; it contracts, and, being more dense than the water below, it descends, and the lighter water from the bottom ascends. Thus, by means of convection currents, the whole of the water is gradually cooled, till its temperature is 4° *C.* Then the water begins to expand, and the colder water is at the surface till solid ice has been formed, which swims on the warmer water below it. The ice is then formed in layers, the number of which increases in proportion to the intensity of the cold at the surface.

161. The expansion of water before its conversion into ice is of great importance. It is owing to this that the great bulk of the water of rivers and lakes is protected from a freezing temperature, which would be fatal to the animals contained in them. This expansion

probably arises from the new arrangement taken by the particles of water on their approach to the state of solidification.

162. The force with which water expands during its conversion into ice is very great. Boyle found that water confined by a moveable plug in a strong brass tube, three inches in diameter, lifted, while it froze, a weight of 74 lbs. with which the plug was loaded. The academicians of Florence burst a small hollow brass globe, the cavity of which was one inch in diameter, by filling it with water, which was afterwards frozen; and it was computed that the force necessary to the bursting of this ball was equal to a pressure of 27,720 lbs.

The following experiment, performed by Major Williams at Quebec, is still more striking. He filled a 12-inch shell with water, and closed it with a wooden stopper, driven in with a mallet. The shell was then exposed to the air, the temperature being $-28°$ *C.* The water froze, and the bung was projected more than 100 yards, while a cylinder of ice, eight inches long, was protruded from the hole.

163. When heat is applied to water at $0°$ *C*, its volume decreases slightly till a temperature of $4°$ *C* has been reached, and from that point it expands as the temperature rises.

Hence a mass of water at $4°$ *C* occupies a smaller space than that which is occupied by the same mass at

any other temperature—that is, the specific gravity of water is greatest at a temperature of 4° *C*, or as it is often expressed, water has its maximum density at 4° *C*.

HOPE'S EXPERIMENT

For measuring the temperature of water at its maximum density.

165. In a vertical glass cylinder, filled with water at 15° *C*, two thermometers are inserted at right angles to the cylinder, one near the top and the other near the bottom. Round the middle of the cylinder is placed a large belt of some freezing mixture. As the water near the middle of the cylinder gets colder, its density increases, and it descends, causing the lower thermometer to indicate a fall of temperature, while the upper thermometer indicates scarcely any change.

FIG. 16.

This goes on till the lower thermometer marks 4° *C*, after which it remains stationary; while the upper thermometer begins to indicate a fall of temperature, and continues to do so till it reaches 0° *C*, when ice begins to form at the surface.

This shows that below the temperature of 4° *C* the water becomes lighter and ascends.

165. Water, when taken as a standard for specific gravities, is taken at its maximum density: that is, the

number, which expresses exactly the specific gravity of a substance, indicates how many times heavier any volume of that substance is than an equal volume of water at 4° *C.*

The French *gramme* is the weight of one cubic centimetre of water at 4° *C.*

166. The melting point of a substance is, like the boiling point, nct independent of the pressure upon it, but the amount of change for a given change of pressure is not nearly so great in the former case as in the latter.

167. A rise of pressure does not always produce a rise in the melting point. If the substance contracts on passing from the liquid to the solid state, its melting point is raised by pressure; but if, like water, it expands when freezing, its melting point is lowered by pressure.

REGELATION.

168. Two pieces of ice placed in contact with each other become frozen together, even if the surrounding medium is warm.

169. There are two explanations offered of this phenomenon :—

(i) A piece of ice is colder in its interior than at its surface. If, therefore, two surfaces are placed in contact, the warmer surface films are surrounded on both sides by a colder body, and will lose heat until an equilibrium

of temperature is established. In cooling below 0° *C*, the surface water is inevitably frozen.

(ii) When two pieces of ice are placed in contact, capillary action on the film of water between them causes them to attract each other. Those parts of the ice which are in contact experience a pressure, and consequently have their freezing point lowered, and melt. This change of state causes an absorption of heat from the surrounding parts, and the liquid film, having its temperature lowered below the freezing-point, freezes.

FREEZING MIXTURES.

170. When snow and salt are mixed together a great quantity of heat disappears, and an intense cold is produced. At the same time, both solids are melted.

The melting is due to some kind of force between the molecules of the snow and those of the salt, and the result of it is the rendering latent a large quantity of heat, such as is invariably the case when a solid becomes a liquid.

171. Many other mixtures may be made to produce cold, but they all depend on the same principles.

172. The converse of the above may be shown, namely, the development of heat when a liquid becomes solid. If a solution of Glauber's salt be made, and saturated with the salt at a high temperature, it will, if well corked and undisturbed, cool down to the tem-

perature of the air without depositing any of the salt in a solid form, although cold water is not ordinarily able to dissolve as much of this salt as hot water.

But if, when it is cold, a thermometer be thrust into the liquid, the whole of the liquid will apparently become suddenly solid, or nearly so, and at the same time the thermometer will show a rise of several degrees.

SECTION X.

GENERATION OF HEAT.

173. That heat is not a substance is certain from the fact that it can be generated by various processes. Such are :—

(*a.*) *Percussion.* When a rifle-bullet is fired at an iron target, the bullet and the target are heated. The *motion* of the bullet is suddenly stopped, and is transformed into *heat;* in other words, the motion of the mass of metal is transformed into motion of its particles.

Again, nails, that are required for brick-work, are made harder by hammering, and it is found that after a few strokes the nail is extremely hot. When cooled, the nail becomes exceedingly brittle, and it will not bear a second hammering.

(*b.*) *Compression.* When bars of metal have been subjected to great pressure between iron rollers, the sheets of metal, as they issue from the rollers, are very hot.

(*c.*) *Friction.* The rubbing together of two pieces of very dry wood produces fire; a marble, rubbed briskly on a hearth-stone, soon becomes hot; the knife-board is quickly warmed by the motion of the knife; water, when rapidly agitated by a paddle-wheel, has its temperature raised; and Sir H. Davy describes an experiment by which, from the friction of ice against ice, at a freezing temperature, each piece of ice was converted into water, the temperature of the water being several degrees higher than that of the ice.

(*d.*) "Twisting or rending bodies asunder generates heat in a very sensible manner. Thus, if a bar of iron or wood be sharply twisted or broken, considerable heat is generated. Buffon observed that if a beam of green timber were supported at one end, and weights were rapidly suspended on the other, so as to bend or break it, a violent hissing ensued, and smoke issued from both ends."—*Herapath.*

(*e.*) *Chemical Mixtures.* The mixture of sulphuric acid and water generates great heat.

On the contrary, when snow and salt are mixed together, a great quantity of heat disappears.

RUMFORD'S EXPERIMENT.

174. The following is a brief account of the experiment that led Count Rumford to conclude that heat is motion:—

Being engaged, in the year 1797, in superintending the boring of canon at the military arsenal of Munich,

he was struck with the very considerable degree of heat which a brass gun acquired in a short time on being bored.

He proceeded to make the following experiment :—

A brass cannon weighing 113 lbs. was made to revolve horizontally with a pressure of about 10,000 lbs. against a blunt steel borer, at the rate of 32 revolutions per minute; and in half an hour the temperature of the metal rose from 60° *F* to 130° *F*.

He then varied the experiment by enclosing the cannon in a box filled with water at 60° *F*, and friction being applied as before, in 2½ hours the water boiled.

The source of the heat generated by friction appearing, from these experiments, to be *inexhaustible,* he was led to conclude that it was impossible to form any distinct idea of anything capable of being excited and communicated in the manner that heat was excited and communicated in these experiments except it was motion.

175. Davy in the year 1799 showed that, by merely expending work in the friction of two pieces of ice, the ice would be melted, and thus obtained a conclusive proof that heat is not a material substance: but it was not till the year 1812 that he made this important statement.

"Heat, or that power which prevents the actual contact of the corpuscles of bodies, and which is the cause of our own sensations of heat and cold, may be defined as a peculiar motion, probably a vibration of the corpuscles of bodies tending to separate them."

176. By the word *corpuscles* Davy names the minute particles, now called *molecules,* the smallest parts into which a substance can be divided without their losing any of the properties of the substance.

These molecules are too small to be perceived with the most powerful microscopes. Millions of millions of water-molecules are contained in a single drop of water.

177. The results of modern investigations lead to the belief that the molecules of every body are in a state of constant motion. In solid bodies the molecules during this motion never get beyond a very minute space. In liquids the molecules have much greater freedom to roam within the bounds of the space occupied by the whole body of liquid. In a gas, the molecules move in straight lines with great velocity; but the number of these minute particles in a single cubic inch of space is so enormous that each molecule is constantly encountering other molecules, and thus has its course changed.—(See *Maxwell's Theory of Heat,* Chap. xxii.)

MEASUREMENT OF WORK.

178. The unit for measurement of work usually employed by British engineers is the foot-pound—that is, the amount of work required to raise a pound weight through the height of a foot.

To find the number of units of work required to raise a weight of 1 ton through the height of 20 feet,

we therefore multiply 2240, the number of pounds in a ton, by 20.

MECHANICAL EQUIVALENT OF HEAT.

179. In the years 1842-1849, Dr. Joule, by experiments at Manchester, found that when water was agitated by means of a brass paddle-wheel, made to revolve by the descent of a known weight, the temperature of 1 lb. of water was raised from 0° *C* to 1° *C* by the expenditure of an amount of force sufficient to raise a weight of 1390 lbs. to the height of 1 foot.

Hence 1390 foot-pounds is the mechanical equivalent of a unit of heat.

180. When heat is supplied to an engine, the work performed is done at the expense of an equivalent amount of heat; this heat is then said to be *converted into the work.*

181. It is not, however, found to be practicable, to convert the whole of the heat which is supplied to an engine into useful work; a great deal is lost by conduction and radiation, and in various other ways, and some of the work is always expended in overcoming the friction of the moving parts, by which it is reconverted into heat and lost.

182. The ratio of the heat converted into useful work to the total heat supplied is called the *efficiency* of the engine, and the largest value hitherto attained in any engine is somewhat below $\frac{1}{8}$.

HORSE-POWER OF STEAM ENGINES.

113. In estimating the *rate of work* in a machine, the work performed by a horse of average strength is taken as a standard or unit of steam-engine power.

It has been determined by careful experiments that a horse's power may be taken as capable of raising 33,000 lbs. 1 foot high in a minute. When we speak, therefore, of an engine of 10 horse-power, we mean that the engine is capable of raising 330,000 lbs. through a vertical distance of 1 foot in a minute.

MISCELLANEOUS EXERCISES.

(1.) A bar of copper weighing 2 lbs., and of specific heat ·095, is heated to 195° *F*, and immersed in 1 lb. of water at 76° *F*. What is the resultant temperature in centigrade degrees?

(2.) State approximately the co-efficient of expansion of air. If a certain quantity of carbonic acid gas occupy 25 cubic inches at 20° *C*, under a pressure of 28·5 inches of mercury, what volume will it occupy at 0° *C*, and under a pressure of 30 inches of mercury?

(3.) Describe a hygrometer and explain its action. The winds which descend from the Alps, when they reach the lower land, are usually very dry. Explain why this is so.

(4.) A thermometer, of which the bulb is made of black glass, and another thermometer of common glass are taken from the same room, and exposed for a short

time to the sunshine. State and explain the difference in the effects.

(5.) Explain the effect of blowing a fire. How is it that you may sometimes increase the heat of a fire by blowing it, and sometimes blow it out?

(6.) Explain clearly what is meant by the phrase that "the latent heat of ice is 79."

(7.) A pound of water, a pound of ice, and a pound of oil, all at 0° *C*, are placed in similar vessels on the same hot plate, and it is found that they take very different times to reach the temperature of 100° *C*. Explain the reasons for this.

(8.) If 5 lbs. of mercury at 58° *C* be mixed with 1 lb. of water at 100° *C*, what will be the temperature of the mixture, the specific heat of water being thirty times that of mercury?

(9.) In determining the boiling point for graduating a thermometer, why is it necessary to take account of the state of the barometer?

(10.) Explain and illustrate what is meant by the capacity for heat of a body.

(11.) A vessel of water heated at the top will boil while the bottom is quite cold: while if heated at the bottom it will not boil until the whole is risen to the boiling point. Explain this.

(12.) A bottle of wine wrapped in a wet cloth and placed in the wind is rapidly cooled. Explain this fact.

(13.) After a clear day, at sunset a fog usually

appears in the valleys or near a river. Explain the reason, and why the fog does not in such a case commonly extend more than a few feet above the ground.

(14.) Why does hot water cool more rapidly in a shallow dish than in a deep one of the same capacity? And why does it cool more rapidly in a draught than in still air?

(15.) If a vessel containing ice be brought into a warm room, its sides usually run down with water. Explain the reason of this.

(16.) A piece of polished brass, a roofing slate, and a piece of white flannel are put in the sunshine for a certain time: which would you expect to find the hottest, and which the coolest? If now they be removed from the sunshine, state the order in which they will regain the temperature of surrounding objects.

(17.) A certain quantity of dry air occupies 1330 cubic inches at 130° *F*, with the barometer at 30·4 inches. What volume will it occupy at 60° *F*, with the barometer at 30 inches?

(18.) A pound of steam at 140° *C* is passed into 10 lbs. of water at 10° *C*. What will be the final temperature, neglecting the heating of the vessel, the latent heat of steam being 536?

(19.) A bar of metal, which at 0° *C* is 1·28 metres long, is placed in a furnace of which it is desired to find the temperature. The co-efficient of expansion of

the metal is ·000017. In the furnace the bar becomes 1·2915 metres long. What is the temperature?

(20.) If 5 lbs. of ice at 32° F be added to 1 lb. of steam at 212° F, what is the resulting temperature?

(21.) Define specific heat. What are the changes in the latent heat of water during its conversion from ice to water and from water to steam?

(22.) What quantity of ice at 0° C will be just melted by 1 lb. of steam at 100° C?

(23.) The co-efficient of expansion of nitrogen is ·0036. Explain what this means. If a bottle filled with nitrogen at the atmospheric pressure at a temperature of 20° C be taken into a room at 0° C, it becomes difficult to take out the stopper. Why is this? If the stopper have an area of two square inches, what force will be needed to remove it, the atmospheric pressure being 15 lbs. on the square inch?

(24.) If 2 ozs. of platinum, after being heated in a furnace, are plunged into 26 ozs. of water at 0° C, and the temperature of the whole becomes 3° C, what was the temperature of the platinum, its specific heat being ·0325?

(25.) One pound of steam, at the temperature of 100° C, is passed through 10 lbs. of water, the temperature of which is 0° C. What will be the temperature of the water after the experiment?

(26.) The sun, on a summer's day, has been shining equally for some time upon windows, some of the sills and frames of which are painted white and others

black. On placing your hand upon the window panes and the differently painted woodwork, will you experience any difference in the warmth of each? If so, explain the cause.

(27.) Clock pendulums are frequently constructed of a rod of steel, to the lower end of which is attached a vessel of glass, partly filled with mercury. Why is this?

(28.) Supposing I desire to raise the temperature of 10 lbs. of water from 32° *F* to 150° *F* by passing into it steam of a temperature of 212° *F*, what quantity, by weight, of steam must I employ?

(29.) The shells employed for projecting molten iron are lined with a thin coating of clay. Why is this?

(30.) Explain why a thermometer, of which the bulb is covered with moist muslin, usually indicates a lower temperature than one which is not so covered.

(31.) State the law of expansion of air for changes of temperature. Two glass globes of *unequal* size are connected by a tube of small bore, in which is sufficient mercury to separate the air in one globe from that in the other. If both globes be equally heated, what effect will be produced on the position of the mercury in the tube? Give the reason for your answer.

(32.) If 6 lbs. of mercury at 50° *C* be mixed with 8 lbs. of water at 100° *C*, find the temperature of the mixture, the specific heat of mercury being ·033.

(33.) What quantity of water at a temperature of 60° *F* will be required to melt 5 lbs. of ice at 32° *F*, so

as to leave the resulting water at the latter temperature?

(34.) If a glass globe contain 2·8 grains of carbonic acid gas at the atmospheric pressure when the temperature is 100° *C*, what quantity will the same vessel hold at the same pressure when the temperature is 150° *C*, neglecting the expansion of the glass?

(35.) Explain what is meant by specific heat. If a bar of bismuth weighing 1 lb. is heated to 100° *C*, and then plunged into 5 lbs. of mercury at 10° *C*, what will be the resulting temperature, if the specific heat of bismuth be ·036 and that of mercury ·033?

(36.) A rod of black marble was used in constructing the pendulum of a clock for the Royal Society of Edinburgh. What was the object of using that material in preference to wood, cooper, or iron; and which of these three would be best adapted to the construction of a pendulum-rod in the absence of the marble?

(37.) When the day is warm you cannot see your own breath; when cold, you can. State the reason.

(38.) A lump of ice is placed in a tall jar of water at 15° *C*. Trace the process by which the whole of the water in the jar is thereby cooled, and point out the limit at which this process ceases.

(39.) What is the difference between a vapour and a cloud? Explain the conditions under which clouds are formed.

(40.) If 12 lbs. of ice at 0° *C* be mixed with 20 lbs.

of water at 100° *C*, what will be the resulting temperature?

(41.) A balloon on passing through a layer of cloud into sunshine immediately rises with increased rapidity. Explain why this is so.

(42.) The specific heat of oil of turpentine being $\frac{3}{7}$ths that of water, what will be the temperature resulting from mixing a pint of turpentine at 0° *C* with an equal weight of water at 30° *C*?

(43.) A house of sheet-iron only is very hot in summer and very cold in winter; but if it be lined with wood, and a small space be left between the iron and wood, it is more uniform in temperature. Explain this.

(44.) How is it shown that water has its greatest density at 4° *C*?

(45.) Of two plants side by side one is covered with a net through which the air can pass quite freely, and the other is uncovered; the night being clear and frosty, the uncovered plant is pinched, but the other escapes. Explain how the net acts to produce this result.

(46.) A piece of slate and a tin plate are laid on snow in sunshine; one gradually sinks into the snow, but the other becomes raised above the general surface on a table of snow. Explain these results, and state which of the two sinks.

(47.) A pound of heated iron is immersed in the same weight of cold water, until the temperature of

both is the same: that of the water is found to have been raised 45° *F.* Give the temperature of the iron at the moment of immersion, the specific heat of that metal being ·11.

(48.) Will it require more heat to raise a given quantity of gas 10° when the pressure is constant, or when the volume is constant? State any general principle to which the answer may be referred.

(49.) A hot bar of copper, weighing 5 lbs., plunged into 25 lbs. of water at 10° *C*, raised its temperature to 29° *C.* What was the temperature of the copper, its specific heat being ·095?

(50.) A litre of nitric oxide when raised in temperature from 0° *C* to 100° *C* is found to increase in tension from 760 millimetres to 1041 millimetres, the volume being the same. Deduce the co-efficient of expansion of nitric oxide.

(51.) Define the dew-point. The dew-point is often much higher in summer than in winter, and at the same time the air is drier. How do you account for this?

(52.) Account for the differences in the sensation produced when the hand is placed upon a blackened iron fender, upon the bright fire-irons, upon the hearth-stone, and upon a log of wood which rests upon the fender.

(53.) Why can I bear my hand longer in hot water if I keep it in one position, than when I move it about?

(54.) Why is the body more sensitive to cold in windy than in calm weather?

(55.) Give a statement of the principles which would guide you in selecting suitable clothing for men proceeding to a hot climate, and for others going to a cold climate.

(56.) A pound of hot iron is immersed in a pound of water at 32° *F*, until both are at 100° *F*. The specific heat of iron being taken as ·1, what was the temperature of the metal at the moment of immersion?

(57.) Supposing that I burn the same absolute quantity of gas monthly, and that this measures 1900 cubic feet when the barometer is at 760 millimetres, how much will it measure when the barometer is at 722 millimetres?

(58.) The specific gravity of a mixture of spirit and water is ·941 at 30° *C*, and ·961 at 0° *C*. Find its coefficient of expansion for 1° *C*.

(59.) If one ounce of platinum heated to 4200° *F*, and plunged into 1 lb. of ice-cold water, raise the water to 40° *F*, find the specific heat of platinum.

(60.) If a certain weight of gas measures 6000 cubic feet when the barometer is at 30 inches, how much will it measure when the barometer is at 28 inches?

(61.) The barometer stands at 30 inches, the thermometer at 25° *C*, and the dew-point is 20° *C*. The pressure of aqueous vapour at 20° *C* in a space saturated by it is ·7 inches. What portion of the pressure indi-

cated by the barometer is due to the pressure of the air? The co-efficient of expansion of a gas is $\frac{1}{273}$.

(62.) Coal mines are frequently ventilated by two shafts, with a fire at the bottom of one of them. Explain how this effects the desired end.

(63.) What is the reason for the occasional formation of a coating of ice over ordinary roads?

(64.) If a solid at temperature T, and whose weight is W, be placed in a quantity of distilled water whose temperature is zero, and whose weight is w, find the common temperature at which the water and the body will ultimately arrive, the specific heat of the body being half that of the water, and no heat being lost or gained by the influence of extraneous bodies.

(65.) A gas measures 98 cubic inches at 220° F. What will it measure at 10° C, under the same pressure?

(66.) A pint of mercury at 126° F is mixed with a pint of water at 212° F. Find the temperature of the mixture, the relative specific heats of mercury and water being as 1 : 30, and their specific gravities as 13 : 1.

(67.) The specific thermal conductivity of wrought iron, a second and an inch being the units of time and space, is ·001. Calculate the number of units of heat lost per hour from each square foot of the surface of a steam boiler, made of wrought-iron plates one-third of an inch thick, the temperature of the inner surface being kept at 120° C, and that of the outer at 100° C.

(68.) Define the phrase "co-efficient of expansion of a gas," and give its numerical value in common use.

250 cub. cent. of hydrogen are measured at 77° *F* and 750 mm. pressure. What would the gas measure at 0° *C* and 760 mm. pressure.

(69.) Two thermometers having been made from equal tubes, it is found that the same divisions serve as a Reaumur scale for the one and as a centigrade scale for the other. What must be the proportion of the quantities of mercury they contain?

(70.) Calculate the specific heat of a substance from the following data:—31·8 gram. of the substance heated to 100° *C*, when immersed in a calorimeter containing 107 gram. of water at 11·09° *C*, caused a resulting temperature of 12·57° *C*.

(71.) A lump of ice at − 4° *C* is placed in a vessel which is immersed in hot water. Trace the changes in the ice as to temperature and volume.

(72.) 2 lbs. of zinc heated to 100° *C* are plunged into 1 lb. of water at 15° *C*, and when the zinc and water have acquired the same temperature, they are at 20° *C*. What is the specific heat of zinc?

(73.) If 1 cubic foot of water cool in contact with air till its temperature is depressed 1°, how many cubic feet of air will have become elevated 1° in temperature, supposing all the heat lost by the water has been transferred to the air. (The density of water is 770 times that of air, and its specific heat is 4 times that of air.)

(74.) A closed glass tube, which when it contains only air may be heated to 300° without bursting, will, if it contains water as well as air, burst before it reaches that temperature. Explain this.

(75.) How is it that ice forms first in pools about blades of grass or straw, and melts first around them?

(76.) Eight ounces of lead at a temperature of 100° *C* are dropped into a vessel containing water at 20° *C*. The heat capacity of the vessel and water being the same as that of 1 lb. of water, what is the specific heat of lead, if the temperature of the water is raised $1\frac{1}{4}$°?

(77.) How do you account for the following phenomena?

(*a*) The coldness of the higher regions of the atmosphere, notwithstanding the great heat that traverses them;

(*b*) The burning of leaves in green-houses by the sun's rays, owing to drops of water resting on the leaves;

(*c*) The great heat experienced in summer in rooms having glass roofs.

(78.) Explain the following common phenomena:—

(*a*) The breaking of a hot plate of cast iron by pouring water on it.

(*b*) The bursting of water-pipes during frost.

(*c*) The chilling effects of wet clothes.

(79.) Define a unit of heat. What is meant when it is said that the latent heat of steam is 536? What quantity of charcoal will be required to boil away entirely a ton of water originally at 31° *C*; every pound of charcoal developing, when burnt, heat enough to raise 8080 lbs. of water 1° *C*?

(80.) State Newton's law of cooling of a hot body. Three vessels, one of bright tin, another of wood, and a third of slate, all of one size, are filled with boiling water and brought into a cold room. Which will cool most rapidly, and which least rapidly, and why?

(81.) Why are alcohol and mercury most frequently chosen for filling thermometers, and the former especially for minimum thermometers?

(82.) Some gas measures 5294 cubic inches at 70° *F*. How much will it measure at 0° *C*?

(83.) A hole is made in the ice on a deep pond, and the temperature observed at various depths from the surface downwards. State how these temperatures will vary, and explain the reason.

(84.) A vessel of bright tin plate, and another of the same size but of porous earthenware, are filled with water and placed in the sunshine. Compare the effects as to the temperatures of the water.

(85.) Of the following, which are good and which bad conductors of heat:—marble, gold, glass, paper, water, air? How would you demonstrate the fact in the case of water?

at all points, and polished bright at the top, but not at the bottom?

(98.) Find the distance through which a weight of 3 lbs. can be raised in England, solely by using for that purpose the amount of heat which would raise the same weight of water at 0° *C* to 5° *C*.

(99.) A man, whose weight is 168 lbs., runs up a staircase of 100 feet in height. How much heat has been consumed out of his body in doing this?

(100.) Equal volumes of alcohol and water cool through the same number of degrees in 2 min. 27 sec. and 5 min. respectively. What is the specific heat of alcohol, its specific gravity being ·81?

APPENDIX.

I.

EXPERIMENTAL DETERMINATION OF THE LINEAR EXPANSION OF SOLIDS.

THE best method of making this determination is that devised by Roy and Ramsden.

A bar, of the material whose expansion it is desired to know, is placed horizontally in a trough *B*, in such a way that one end of it is kept firmly fixed in any desired position, while the other end is free to move as the bar alters in length by expansion or contraction.

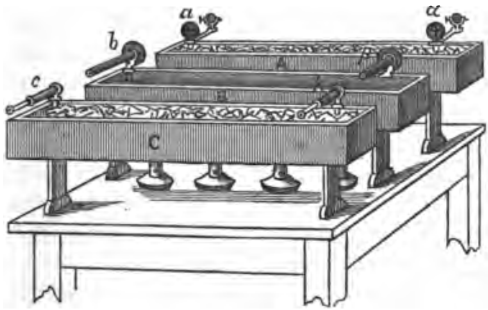

FIG. 17.

The trough can be filled with ice, and is capable of being heated by lamps or flames beneath it. Each end of the bar carries, by means of a vertical support, a lens of rather long focal length, *b* and β, whose distance

apart can be very accurately determined. On one side of this arrangement is placed a similar trough A, containing a bar which carries corresponding vertical supports at its extremities surmounted by rings, a and α, with cross wires. Images of these cross wires are formed by the lenses b and β on the other side of B at the points c and κ, and are there viewed by two lenses of short focal length, which have each a pair of cross wires fixed permanently in their foci, so as to be seen at the same time as the image of the wires on A. Each system forms as it were a telescope, of which the lens on the bar B is the object-glass, and the lens on the bar C the eye-piece. The supports on A and C are maintained accurately in their relative positions by keeping the bars on which they are fixed surrounded by ice. After the images of a and c have been once made to coincide, any movement of the lens b will cause a displacement of the images, and, in order to readjust them, the lens must travel back the same distance by which it has been displaced. The same reasoning applies to the set α, β, κ. Now the lens b is rigidly fixed on its support, and therefore any adjustment of its position can only be effected by moving the whole bar; the lens β is, on the contrary, mounted on a very fine and accurate screw attached horizontally to the end of the bar, which, by giving to it a lateral movement, can bring it into position without moving the bar itself.

In making an experiment, both lenses are first brought into position when the bar B is surrounded by melting ice, so as to give it a temperature of 0° C. Heat is then applied to the middle trough, and the rise in temperature registered by thermometers. When a certain tempera-

ture is reached, the lens b is first readjusted, and then the lens β is brought again into position by means of the screw, and at the same time the amount of its displacement is determined by the number of turns given to the screw. The distance travelled back by the lens β is evidently the expansion which the bar has undergone when heated through the number of degrees registered by the thermometer.

II.

EXPANSION OF LIQUIDS.

1. The apparent expansion of mercury, or any liquid, may be determined in the following manner :—

A glass reservoir with a bent open neck is filled with mercury at 0° C, and the weight of the contained mercury, W, ascertained. Its temperature is then raised to 100° C, and the weight, w, of the expelled mercury determined.

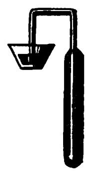

FIG. 18.

Suppose V_0 is the volume of the instrument and of its contained mercury at 0° C. At 100° C these volumes will have changed unequally : let V be the volume of the glass, and V' that of the mercury, then $V'-V$ will be the increase in volume of the mercury above that of the glass, and $\frac{V'-V}{V}$ is the *apparent expansion* of the liquid. But the weight of the volume

$V'-V$ of mercury is w, and the weight of the volume V of mercury remaining in the tube is $W-w$; these weights are proportional to the volumes, so that

$$\text{apparent expansion} = \frac{V'-V}{V} = \frac{w}{W-w}.$$

2. This instrument can be used for determining temperatures, and is then called the *weight thermometer.*

For since $\frac{w}{W-w}$ represents the expansion for 100 degrees, the expansion for one degree will be

$$\frac{w}{100(W-w)}.$$

If, then, in another experiment, when the instrument is heated to t° C, a weight u of mercury is expelled, the total expansion for t° will be $\frac{u}{W-u}$, and therefore, by dividing this quantity by the expansion for one degree, we get

$$t = \frac{u}{W-u} \div \frac{w}{100(W-w)} = .100\frac{u}{w}\cdot\frac{W-w}{W-u}.$$

3. The co-efficient of *absolute expansion* of mercury has been obtained by methods too complicated in their detail for this treatise, but one method may be shortly referred to, which depends on the following principles :—

If a weight W of mercury occupies the volume V_0 at 0° C, and the volume V_t at t° C, and if its specific gravity

at those temperatures be S_0 and S_t respectively, we have (*See Hydrostatics*, Art. 46) :—

$$W = V_0 S_0 = V_t S_t ;$$

and therefore

$$\frac{S_0}{S_t} = \frac{V_t}{V_0} = 1 + \delta_t \text{ where } \delta_t \text{ is the expansion for}$$

t degrees (for $V_t = V_0 (1 + \delta_t)$). Compare Art. 48.

So that, if we can ascertain the specific gravity of mercury at 0° C and at t° C, we can find its expansion between those temperatures.

Now if two vertical columns of liquid are connected together at the bottom by a fine horizontal tube, the levels of their surfaces from the axis of the tube will be inversely as the specific gravities of the liquids: so that if two vertical tubes connected at their bases are partly filled with mercury, and one tube is kept at the temperature 0° C while the other is raised to t° C, their surfaces will be at distances h_0 and h_t from the bottom tube, and we get

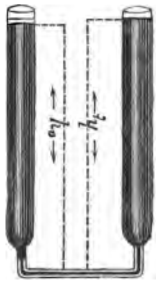

FIG. 19.

$$\frac{h_t}{h_0} = \frac{S_0}{S_t} = 1 + \delta_t ;$$

and therefore

$$\delta_t = \frac{h_t - h_0}{h_0}.$$

The objection to this process lies in the necessity for leaving the top of the mercury columns more or less exposed in order to be able to see them and measure their levels. Regnault's method, which is, however, too complex to be introduced here, entirely obviates this difficulty.

EXERCISES ON THE EXPANSION OF LIQUIDS.

The following Table exhibits the expansion of mercury from 0° *C* and water from 4° *C* for every degree between 0° *C*, and 30° *C*, and for every 10° above, up to 100° *C*.

Temperature.	Volume occupied by the mass of mercury which has unit of volume at 0° *C*.	Volume occupied by the mass of water which has unit of volume at 4° *C*.	Temperature.	Volume occupied by the mass of mercury which has unit of volume at 0° *C*.	Volume occupied by the mass of water which has unit of volume at 4° *C*.
0°	1·0000000	1·0001269	19°	1·0034101	1·00158
1	1·0001790	1·0000730	20	1·0035901	1·00179
2	1·0003581	1·0000331	21	1·0037702	1·00200
3	1·0005372	1·0000083	22	1·0039502	1·00222
4	1·0007164	1·0000000	23	1·0041304	1·00244
5	1·0008956	1·0000082	24	1·0043106	1·00271
6	1·0010749	1·0000309	25	1·0044908	1·00293
7	1·0012542	1·0000708	26	1·0046711	1·00321
8	1·0014336	1·0001216	27	1·0048514	1·00345
9	1·0016131	1·0001879	28	1·0050318	1·00374
10	1·0017925	1·0002684	29	1·0052123	1·00403
11	1·0019721	1·0003598	30	1·0053928	1·00433
12	1·0021516	1·0004724	40	1·0072004	1·00773
13	1·0023313	1·0005862	50	1·0090132	1·01205
14	1·0025110	1·0007146	60	1·0108310	1·01698
15	1·0026907	1·0008751	70	1·0126539	1·02255
16	1·0028705	1·0010215	80	1·0144818	1·02885
17	1·0030503	1·0012067	90	1·0163147	1·03566
18	1·0032302	1·00139	100	1·0181527	1·04315

NOTE. The same mass of ice at 0° *C* has the volume 1·090821.

EXAMPLES FOR PRACTICE.

(1.) The density of mercury at 0° *C* being 13·596, what is its density at 100° *C*?

(2.) A barometer column at 15° *C* measures 30 inches; what length of column represents the same pressure at the temperature 0° *C*?

(3.) A barometer with a brass scale true at 0° *C* gives a reading of 29·571 inches at 16° *C*; what is the true length of the column of mercury at 0° *C* which would give the same pressure?

(4.) Suppose a thermometer to have a perfectly uniform calibre, how much longer should the division between 99° and 100° be than that between 0° and 1°? See Art. 39 (v.).

(The mean co-efficient of expansion of mercury up to 99° *C* is 0·0001815.)

(5.) A weight thermometer contains 3290 grains of mercury at 0° *C*; and 50 grains are expelled when the temperature is brought to 100° *C*. Deduce the co-efficient of apparent expansion of mercury.

(6.) Using the same instrument to determine the temperature of an enclosed space, 25·2 grains of mercury were expelled. What was the temperature of the enclosure?

(7.) Assuming the co-efficient of apparent expansion of mercury obtained from No. (5), what weight of mercury will be expelled at 100° from a weight thermometer which contains 1974 grains at 0° *C*?

(8.) A weight thermometer contains 1622 grains of mercury at 0°, and 24·5 grains are expelled at 100° *C*. What temperature is represented by an expulsion of 1·764 grains?

(9.) What will be the weight of the quantity of mercury which at 20° *C* has the same volume as half a pound of platinum at the same temperature?

Specific gravity of mercury at 0° *C* = 13·596

Specific gravity of platinum at 0° *C* = 22·000.

(10.) The specific gravity of a body is equal to the ratio of its weight to that of an equal bulk of pure water at 4° *C.* Also, when a body is immersed in water, it loses the weight of its own volume of water. If, then, a pound weight of brass, when immersed in water at 21° *C*, loses a weight of 1·9032 ounces, what is the specific gravity of the brass at 0° *C*?

(11.) The specific gravity of a specimen of platinum at 0° *C* is 19·362. Find the ratio of the weights of equal volumes of platinum and of mercury at 100° *C*, and express the result as a decimal fraction.

(12.) In an experiment for the determination of the absolute expansion of mercury, the length of the hotter column at 100° *C* being 16·3405 inches, what was the length of the column at 0° *C* which balanced it?

(13.) If the diameter of a thermometer tube equals ·1 of an inch, and its length 10 inches, what must be the capacity of the bulb in order that the instrument may register temperatures ranging between 250° *C* and − 30° *C*?

III.

SPECIFIC HEAT.

1. The *specific heat* of a substance is the ratio of the capacity for heat of any quantity of it to its mass.

Call the capacity for heat of a body C, its mass M, and its specific heat S, we get

$$S = \frac{C}{M}.$$

If we take one pound, or one kilogramme, of a substance, that is, make $M = 1$, then $S = C$, and we may define the specific heat of a substance to be the capacity for heat of one pound, or one kilogramme, of the substance, as the case may be.

Since, in the case of water, $C = M$ and $S = 1$, the capacity for heat of a body is also equal to the quantity of heat required to raise any weight of that substance $1°\ C$, to the quantity of heat required to raise an equal weight of water from $0°\ C$ to $1°\ C$.

2. Since the unit of heat is always made dependent on the unit of mass, the first and last definitions are true whatever be the units employed.

NOTE.—*Specific heat-capacity* is proposed as a better term than *specific heat*, as one that expresses more definitely the thing signified, and as one that would involve little or no inconvenience in the change of title.

IV.

REGNAULT'S CALORIMETER.

A calorimeter for determining specific heats by the method of mixtures, consists of a thin brass or silver vessel, highly polished on the outside, to prevent as far as possible loss of heat from radiation.

This is supported either on three ivory pins or on strings of worsted inside another similar vessel burnished on the inside. In this way conduction of heat to or from the calorimeter is very much prevented; and any heat which may be radiated from one surface will be reflected back by the other polished surface.

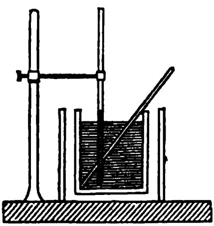

FIG. 20.

There must always be a certain proportion of the heat absorbed by the calorimeter itself, and by the thermometer used to ascertain the change of temperature. This has to be determined in a preliminary experiment, and allowed for. This operation, which is called "reducing the calorimeter to water," consists in determining the heat-capacity of the calorimeter, and is performed as follows:—

The calorimeter is partly filled with a weight w of water, and its temperature t is observed. A weight w' of hot water, of temperature t', is then introduced into it, and the temperature θ of the mixture is then ascertained. Then we have—

Heat lost by the hot water = heat gained by calorimeter and its contents, or if c be the capacity of the calorimeter and thermometer,

$$w'(t'-\theta) = w(\theta - t) + c(\theta - t),$$

whence

$$c = w'\frac{t'-\theta}{\theta - t} - w.$$

If, now, a body whose weight is w', and whose specific heat-capacity S it is required to know, be heated to t'° and dropped into the calorimeter, we get

HEAT LOST.		HEAT GAINED.
$S.\ w'.\ (t'-\theta)$	$=$	$(w + c)\ (\theta - t)$

$$\text{whence } S = \frac{w+c}{w'}\cdot\frac{\theta - t}{t'-\theta}.$$

V.

CONDUCTION.

The method used to determine the conductivity of a bar is to compare the flow of heat across any section of it with the rate of the decrease in temperature at that section. The former can be measured, as shown in Article **100**, by determining the total loss of heat from radiation and convection on the cooler side of it, and the latter by registering the temperature of different parts of the bar by thermometers inserted into holes drilled in the bar, and surrounded by fluid metal.

VI.

VAPOUR TENSION OF WATER AND DEW.

1. The maximum pressure for water-gas at various temperatures has been accurately ascertained by Regnault; some of his results are given in the following table:—

Temperature Centigrade.	Pressure in inches of mercury.	Temperature Centigrade.	Pressure in inches of mercury.
− 10°	0·082	55°	4·622
− 5°	0·122	60°	5·854
0°	0·181	65°	7·354
5°	0·257	70°	9·170
10°	0·361	75°	11·350
15°	0·500	80°	13·951
20°	0·684	85°	17·034
25°	0·927	90°	20·669
30°	1·241	95°	24·929
35°	1·646	100°	29·898
40°	2·160	105°	35·660
45°	2·809	110°	42·300
50°	3·619	115°	49·940

Observe in the first place that water below the freezing point, that is while in the solid state, gives off gas of a sensible pressure; and, in the second place, that the maximum pressure at 100° *C*, that is at the ordinary boiling point of water, is very nearly indeed 30 inches, the average pressure of the whole atmosphere.

2. The atmosphere always contains more or less water-gas, the result of evaporation from exposed

surfaces of water: but, as it consists of other kinds of gas as well, and the evaporation is consequently slow, the pressure of the water-gas is not necessarily the maximum pressure for the temperature of the air.

For instance, on a warm day the temperature of the air may be 20° *C*, for which the tension or pressure of water-gas should be 0·68 inches; but in consequence of the slowness of the evaporation, the actual tension of the gas may be only 0·50 inches, corresponding to a temperature 5° lower.

Under these circumstances the air may have its temperature *slightly* altered without affecting the pressure of the water-gas which forms part of it. But if its temperature be lowered more than 5°, it will pass through the temperature for which the pressure of its water-gas is the maximum, and consequently some of the water will be reconverted to the liquid form, until its pressure is readjusted to the lower temperature.

3. It is evident then that, if we have a table showing the maximum pressures of water-gas for various temperatures, we can ascertain the actual pressure of the vapour in the air at any time, by observing the temperature at which the gas is partially liquefied when it is cooled down. This temperature is called the *Dew-Point.*

DEF. The dew-point may therefore be defined as *the temperature for which the existing pressure of the water-gas forming part of the atmosphere is the maximum.*

or of a gas or lamp flame burning. Careful measurements have been made, of which the following are a few instances :—

A pound of	Hydrogen	burning in Oxygen	gives out	34,462	Therms.
,,	Carbonic Oxide	,,	,,	3,403	,,
,,	Marsh Gas	,,	,,	13,063	,,
,,	Olefiant Gas	,,	,,	11,857	,,
,,	Carbon	,,	,,	8,080	,,

IX.

SPECIFIC HEAT-CAPACITIES OF GASES.

1. In accordance with the definition given in Article 60, the specific heat-capacity of a gas should be measured by the number of Therms which will raise one pound of it from 0° C to 1° C; but if the formula of Article 46 be examined, it will be seen that the temperature of a gas can be raised by heat under more than one set of conditions, namely :—

(*a*) The pressure remaining the same, the volume may be changed with the temperature.

(*b*) The volume remaining the same, the pressure may be changed with the temperature.

(*c*) The pressure and volume may both change in any way, so that their product varies with the absolute temperature.

A little consideration will show that the value under the conditions (*a*) will probably be greater than the value under the conditions (*b*); because in the former case the external pressure will resist the expansion, and

therefore work will have to be done, while in the latter there is no change of volume, and therefore no work against external forces.

2. Regnault has made the determination of the specific heat-capacity of air under constant pressure, (*a*), by means of a special calorimeter, and has found the number to be 0·2379.

3. The value under conditions (*b*) has never yet been directly determined by experiment, but it may be calculated in several ways, one of which is the following:—

4. Suppose the air is confined in a cylindrical vessel one square foot in section by a piston which weighs nothing, and can move up and down without friction; and suppose the piston be at the level *a*, one foot from the bottom, when the pressure of the air upon it equals that of a column of mercury 30 inches high at 0° *C*. Now the density of mercury at 0° $C = 13{\cdot}596$, and a cubic foot of water at 4° *C* weighs 62·425 lbs.; therefore the pressure on the piston

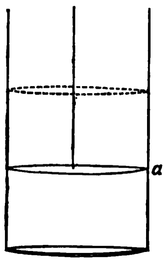

FIG. 21.

$$= 62{\cdot}425 \times 13{\cdot}596 \times 30 \div 12 \text{ lbs.}$$
$$= 2122{\cdot}076 \text{ lbs.}$$

If the air be now doubled in volume by heating it through 273° *C* (supposing the cylinder itself is inexpansible), the piston will have been pushed back through one foot, and therefore an amount of work equal to 2122·076 foot-pounds will have been done by the gas, representing an expenditure of heat equal to

$$\frac{2122{\cdot}076}{1390} = 1{\cdot}526673 \text{ therms.}$$

Again, a cubic foot of air under standard conditions weighs 0·0809379 lbs., and as the specific heat-capacity of air under constant pressure = 0·2379, the total number of therms used in this expansion will be

$$0{\cdot}0809379 \times 0{\cdot}2379 \times 273 = 5{\cdot}256583.$$

Out of these 1·526673 will have done the work of expansion against the constant pressure; therefore 2·72991 therms will be the heat which has been employed simply in raising the temperature of the gas 263° *C.*

From this we therefore find the number of therms which will raise 1 lb. of air 1° *C* without doing work against external pressure to be

$$3{\cdot}72991 \div (0{\cdot}0809379 \times 273) = 1{\cdot}6881.$$

5. In making this calculation, it has been assumed that air is not altered in temperature when it expands, if it does not resist external pressure, or, in other words, do external work. This assumption is justified by an experiment of Joule's, who found that air, when expanding into a vacuum, was on the whole neither heated nor cooled.

ANSWERS TO EXERCISES.

SCALES OF TEMPERATURE (Page 14).

(1.) (i) $-1\frac{1}{9}°$; $-\frac{8}{9}°$. (ii) $7\frac{2}{9}°$; $5\frac{7}{9}°$. (iii) $13\frac{1}{3}°$; $10\frac{2}{3}°$. (iv) $-17\frac{7}{9}°$; $-14\frac{2}{9}°$. (v) $-21\frac{2}{3}$; $-17\frac{1}{3}°$. (vi) $-42\frac{7}{9}°$; $-34\frac{2}{9}°$.

(2.) (i) $6\frac{1}{4}°$; $43\frac{1}{4}°$. (ii) 25°; 77°. (iii) 0°; 32°. (iv) $-22\frac{1}{2}°$; $-8\frac{1}{2}°$. (v) $-80°$; $-112°$. (vi) 150°; 302°.

(3.) (i) $60\frac{4}{5}°$; $12\frac{4}{5}°$. (ii) 113°; 36°. (iii) 230°; 88°. (iv) 32°; 0°. (v) 5°; $-12°$. (vi) $-11\frac{1}{5}$; $-19\frac{1}{5}°$.

(4.) 50° Fah.

(5.) 10° Cent. and 50° Fah.

(6.) 10° Cent. and 50° Fah.

(7.) $-40°$.

(8.) Make each degree $\frac{4}{5}$ths that on Fah.

(9.) 20° Cent., 68° Fah.

(10.) 80° Fah.

(11.) 20° Cent., 68 Fah.

(12.) $-11\frac{3}{7}°$ Cent., $11\frac{3}{7}°$ Fah.

(13.) 24°.

(14.) 23°.

(15.) 59° Fah., 12° Reaum., and if d be the number of degrees, Fah. rises $\frac{9d}{5}$ and Reaum. $\frac{4d}{5}$.

(16.) $137\frac{1}{2}°$.

(17.) 122° Fah.

EXPANSION OF GASES (Page 30).

(1.) 5·4 ft.
(2.) 21·375 ft.
(3.) 1615 cub. ft.
(4.) 939 cub. in.
(5.) $272{\cdot}\dot{7}\dot{2}^\circ$.
(6.) $71\frac{137}{318}$ cub. in.
(7.) $1\frac{241}{2689}$ cub. ft.
(8.) 15·34·· in.
(10.) 6048·6·· cub. ft.
(11.) $1\frac{359}{12385}$.
(12.) $149\frac{1}{7}$ cub. in.
(13.) $273\frac{41}{183}^\circ$.
(14.) $5{\cdot}370\dot{6}$ cub. ft.
(15.) $28\frac{4}{5}^\circ$ Cent. nearly.
(16.) 0·002036.
(17.) 273° Cent.

EXPANSION OF SOLIDS (Page 35).

(1.) 15·00703125 ft.
(2.) 8·501838125 ft.
(3.) 5·502695 ft.
(4.) 12·009261 ft.
(5.) 16·002344 in.
(6.) 150·091875 ft.
(7.) 57·7676859375 miles.
(8.) 28·007775 in.
(9.) 29·998562 in.
(10.) 0·00001441347.
(11.) 124·75° Cent.
(12.) 1 c. m. division = 0·3935813 in.
(13.) 30·000073 in., and 35·9527 in.
(14.) 0·00001225.
(15.) 15·026625 sq. ft.
(16.) 48·1617072 sq. ft.
(17.) 23·5306299 sq. ft.
(18.) 11539·75104 cub. in.
(19.) 1442·717 cub. in.
(20.) 50·01595 cub. in.
(21.) 15·39345 cub. in.
(22.) 993·8836 grains.
(23.) 10·44···
(24.) 8·364···
(25.) 11·289···
(26.) 245·826875 cub. ft.
(27.) 28·541895 cub. ft.
(28.) 12·901.
(29.) 15° nearly.
(30.) −272°·85 Cent. and −459°·13 Fah.

CALORIMETRY (Page 54).

(1.) $49\frac{6}{11}^\circ$.
(2.) $39\frac{2}{17}^\circ$.
(3.) 135.
(4.) 11·88.
(5.) 27·1°··
(6.) 25.
(7.) 10·904.
(8.) 37·09°··
(9.) $39\frac{1}{16}$ lb.

(10.) ·056.	(11.) 12744·48 lbs.	(12.) ·033018····
(13.) ·11.	(14.) 990.	(15.) 11520.
(16.) 19080.	(18.) 72000.	(19.) 1040.
(20.) $1\frac{1}{79}$ lb.	(21.) $1\frac{78}{159}$ lbs.	(22.) $48\frac{12}{13}$° Cent.
(23.) 100°.	(24.) 76°.	(25.) 79·5.
(26.) $2\frac{4}{11}$°.	(27.) 0·05576.	

CONDUCTIVITY (Page 70).

(1.) 0·0092.
(2.) 5·256.
(3.) 0·007118 and 49200 therms nearly.
(4.) 91·6 lbs.

MISCELLANEOUS EXERCISES (Page 97).

(1.) 35°.	(2.) $22\frac{151}{1172}$ cub. in.	(8.) 94° Cent.
(17.) 1187·6 cub. in.	(18.) $70\frac{6}{11}$°.	(19.) 528·4° Cent.
(20.) 104·3° Fah.	(22.) $8\frac{4}{79}$ lbs.	(23.) 2·014 lbs.
(24.) 1203° Cent.	(25.) $57\frac{9}{11}$° Cent.	(28.) $1\frac{383}{2567}$ lbs.
(32.) 98·79 Cent.	(33.) $25\frac{11}{28}$ lbs.	(34.) 2·469··· grs.
(35.) $26\frac{8}{67}$° Cent.	(40.) $32\frac{7}{8}$° Cent.	(42.) 21° Cent.
(47.) $486\frac{1}{11}$° Cent.	(49.) 1029° Cent.	(50.) 0·003684.
(56.) 780° Fah.	(57.) 2000 cub. ft.	(58.) 0·000708···
(59.) 0·0307.	(60.) $6428\frac{4}{7}$ cub. in.	(61.) 29·3 inches.
(64.) $\frac{WT.}{W+2w.}$	(65.) 73·47··· cub. in.	(66.) 186° Fah.
(67.) 31104.	(68.) 226·01··· cc.	(70.) 0·057···
(72.) 0·03125.	(73.) 3080.	(76.) 0·0317.
(77.) 0·605 nearly.	(79.) 167·72 lbs.	(82.) 4914 cub. in.
(89.) ·000025 and 0·000182.	(90.) 8940 therms and $113\frac{13}{79}$ lbs.	(91.) 10414·6··· oz.
(93.) 66° Cent.	(94.) $27\frac{63}{67}$ lbs.	(96.) $26{\cdot}920\dot{6}$ lbs.
(98.) $2316{\cdot}\dot{6}$ lbs.	(99.) $12\frac{12}{139}$ therms.	(100.) 0·065 nearly.

EXPANSION OF LIQUIDS (Page 117).

(1.) 13·3533.

(2.) 29·9195 in.

(3.) 29·495 in.

(4.) $\frac{184}{179}$ or $1\frac{5}{179}$ths of the degree between 0° and 1°.

(5.) $\frac{1}{6480}$.

(6.) 50° Cent.

(7.) 30 grains.

(8.) 7·1° Cent.

(9.) 4·9289 ounces.

(10.) 8·4.

(11.) 1·44948.

(12.) 16·05 inches.

HYGROMETRY (Page 125).

(1.) 12·328 grs.

(2.) 21·364 grs.

(3.) 27·685 grs.

(4.) 28·893 in.

(5.) (*a*) Weight of displaced air = 3·46 grs.

(*b*) " " = 3·438 grs.

∴ Difference = 0·022 grs.

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